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THE RELATION OF SPECIFIC GRAVITY TO HATCHING POWER IN EGGS OF THE DOMESTIC FOWL

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During the progress of studies on the relation of density and morphology of sperm to fertility and hatchability, the author noticed that thin shelled eggs appeared to hatch poorly. Such a possibility was, of course, quite logical, since thin shelled eggs not only lose considerable moisture during incubation but the amount of calcium in the shell which the embryo draws upon for bone formation is low. It is, of course, only the thinnest of shells which from external appearance can be recognized as weak. The thought occurred that this relation between hatching power and shell strength might extend farther up the scale, and hatchability might possibly be appreciably less in eggs which were thinner or weaker than average, but not sufficiently so to be externally recognizable. Most tests for strength or thickness of shell involve physical or chemical tests which require the egg to be broken. However, the specific gravity test of Olsson (2) provides a measure of percentage shell without injury to the intact egg. When this test was brought to the author's attention an extensive experiment was planned with the object of correlating percentage of shell in the individual egg with its hatching power.

MATERIALS AND METHODS

During the regular hatching season of 1939 all eggs laid by a number of our regular Barred Rock and White Leghorn breeding pens, were tested for specific gravity by immersing them in a series of twelve salt solutions varying in density from 1.058 to 1.102 with a class range of 0.004. The specific gravity of each egg was regarded as equal to that of the lowest solution in which it would float just beneath the surface. The eggs were tested each morning following the day of laying, stored in the regular holding cabinet and set together once each week in the same mammoth incubator. Infertiles and dead germs were removed on the seventh day and dead embryos on the eighteenth day, when the eggs were placed in the regular pedigree hatching baskets; they were pedigreed according to hen and date laid and thus a hatching record was secured on each individual egg. All eggs laid over a period of five weeks were incubated and recorded in this manner.

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EXPERIMENTAL RESULTS

Hatching records on the pooled data based on 2957 Rock and 2687 Leghorn eggs, classified according to specific gravity, are shown in Table 1.

It can be seen that there is a distinct tendency for hatchability to fall off in the lower classes. This is especially true in the Barred Rocks below 1.078 and in the Leghorns below 1.086. The results of this experiment have been substantiated in a number of subsequent trials on eggs from different groups of hens in different seasons. In these trials the two points

TABLE 1.—RELATION BETWEEN SPECIFIC GRAVITY OF THE EGG AND HATCHABILITY. POOLED DATA COLLECTED IN 1939

	BARRED ROCKS				WHITE LEGHORNS			
Specific gravity	Eggs set	% fertile	% fertile hatched	% total hatched	Eggs set	% fertile	% fertile hatched	% total hatched
1.054	6	83.3	20.0	5.6	—	—	—	—
1.058	8	87.5	0.0	0.0	6	33.3	0.0	0.0
1.062	15	86.7	30.0	20.0	4	50.0	0.0	0.0
1.066	44	88.6	52.8	43.2	9	77.8	42.9	33.3
1.070	130	84.6	53.6	45.4	23	78.3	55.6	43.5
1.074	230	81.3	51.9	42.2	42	78.6	57.6	45.2
1.078	463	80.8	75.9	61.3	96	57.3	69.1	39.6
1.082	835	82.5	79.4	65.5	235	79.1	62.4	49.4
1.086	778	81.4	86.9	74.0	529	83.6	84.8	70.9
1.090	367	86.4	86.4	74.7	929	88.6	90.0	79.8
1.094	74	78.4	86.2	67.6	568	91.5	89.4	81.9
1.098	7	57.1	100.0	57.1	209	90.0	83.5	75.1
1.102	—	—	—	—	37	94.6	74.3	70.3
Total	2957	82.4	78.0	64.7	2687	86.0	84.4	72.6

mentioned above, viz., 1.078 in Rocks and 1.086 in Leghorns, consistently marked the lower limit of the best hatching eggs irrespective of the general level of hatchability. These points, i.e., 1.078 for Rocks and 1.086 for Leghorns will be referred to henceforth as the critical points. The relationship between specific gravity and hatchability is shown graphically in Figures 1 and 2.

Table 2 summarizes the results of five separate tests on a total of 5372 eggs. The eggs have been grouped according to those above and those below the critical point for the breed in question, those above being designated as having passed and those below as having failed in the specific gravity test. The five lots show an average difference between those passing and those failing of 7.8 in percentage fertility, 32.4 in percentage fertile eggs hatching, and 29.7 in percentage total eggs hatching. An average of 22% of the eggs failed to pass, and by discarding these before setting, hatchability of total eggs would be improved 8.3%.

Simple inspection of the data thus far presented shows that hatchability (percentage hatch of fertile eggs) falls off definitely and appreciably below the critical points. However, the relationship between fertility and specific gravity is not so definite. In the following sections the various

aspects of the problem will be dealt with separately and the interpretations made and conclusions reached will be benefited by appropriate statistical analyses.

Specific Gravity and Fertility

If there were no relation between specific gravity and fertility, the data in Table 1 should show, within the limits of the random sampling error, the same proportion of fertile eggs in all specific gravity classes. The 2957 Barred Rock eggs are 82.38% fertile, and if this percentage figure is used as the basis for calculating the expected numbers of fertile eggs in each class, the χ^2 test for goodness of fit can be applied to determine whether the observed frequencies do in fact conform to those expected on

TABLE 2.—SUMMARIZED RESULTS OF SPECIFIC GRAVITY TESTS FOR HATCHABILITY

First test—Regular hatching season—Eggs set March and April, 1939

BARRED ROCK BREEDERS

No. of eggs set			% fertile	% fertile hatch	% total hatch
Passing test	—	1915	82.8	87.3	72.2
Failing test	—	340	79.7	55.7	44.4
Total	—	2255	82.3	82.3	66.7

WHITE LEGHORN BREEDERS

Passing test	—	2198	88.4	87.9	77.7
Failing test	—	351	72.6	62.7	45.6
Total	—	2549	86.2	85.0	73.2

Second test—Eggs set June, 1939

BARRED ROCK PULLETS

No. of eggs set			% fertile	% fertile hatch	% total hatch
Passing test	—	298	84.5	66.7	56.3
Failing test	—	20	88.5	37.0	32.8
Total	—	318	84.9	63.5	53.9

Third test—Eggs set Sept., 1939

BARRED ROCK BREEDERS

No. of eggs set			% fertile	% fertile hatch	% total hatch
Passing test	—	80	91.3	74.0	67.5
Failing test	—	32	81.3	30.8	25.0
Total	—	112	88.4	62.6	55.4

WHITE LEGHORN BREEDERS

Passing test	—	74	89.2	86.4	77.0
Failing test	—	64	75.0	54.2	54.2
Total	—	138	82.6	72.8	60.1

this basis. Table 3 *(a)* shows the detail of this analysis and it can be seen that the χ^2 obtained was 2.022 whereas it should be as high as 19.675 to reach the .05 point. The data therefore are in agreement with the assumption that no relationship exists between specific gravity and fertility. In the case of the Leghorns Table 3 *(b)* the χ^2 obtained was 17.341 which, although much greater than in the Rocks, still does not reach the .05 point of 19.675.

A more critical method of testing this point, however, is to compare the average specific gravity of the fertile eggs with that of the infertiles from each hen. One obtains in this way a series of paired observations which can be analysed by "Students" method, the results obtained being independent of the variations between hens. The results of such an

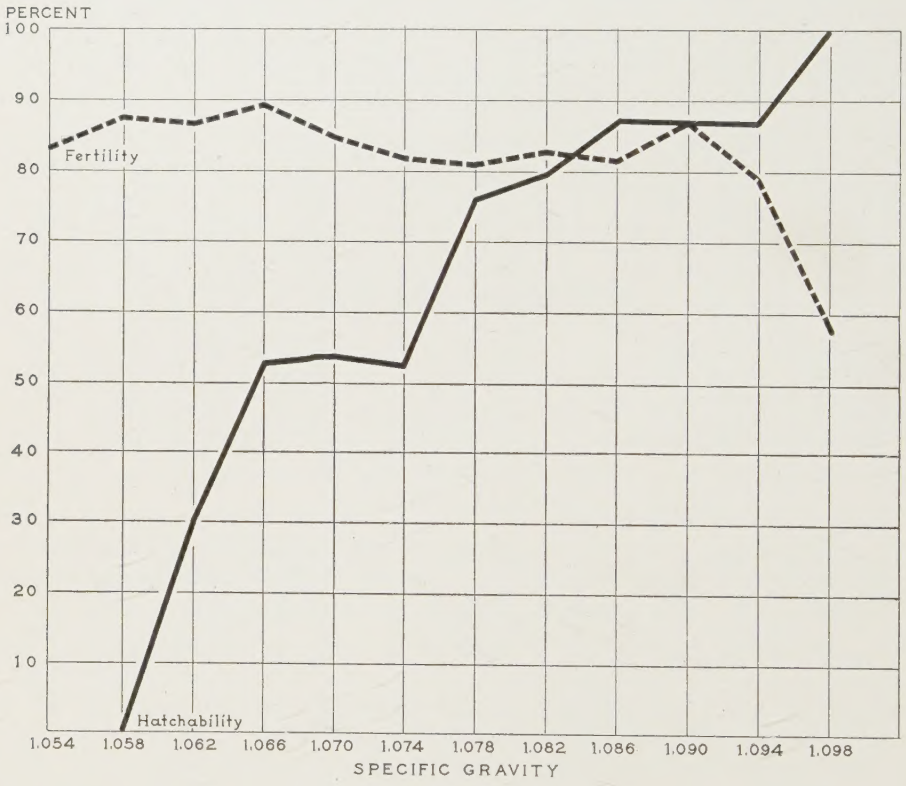

FIGURE 1. Relation of specific gravity of the egg to fertility and hatchability in Rocks.

analysis are shown in Table 4 *(a)*, and it can be seen that in both breeds the fertile eggs are slightly higher in specific gravity than are the infertiles. In the Rocks the difference is not statistically significant but in the Leghorns the *t* value is slightly in excess of the .05 point.

It would appear, therefore, that infertile eggs tend to be lower in specific gravity than fertile eggs but the difference is not marked.

TABLE 3.—RESULTS OF χ^2 TESTS FOR GOODNESS OF FIT. COMPARISON OF OBSERVED NUMBERS OF FERTILE EGGS WITH THOSE EXPECTED IF FERTILITY WERE EQUAL IN ALL SPECIFIC GRAVITY CLASSES.

(a) BARRED ROCKS

Specific gravity	1.054	1.058	1.062	1.066	1.070	1.074	1.078	1.082	1.086	1.090	1.094	1.098	
Fertile eggs observed	5	7	13	39	110	187	374	689	633	317	58	4	2436
Fertile eggs expected	4.94	6.59	12.36	36.25	107.09	189.47	381.42	687.87	640.92	302.33	60.96	5.77	2435.9
χ^2	.0007	.0255	.0331	.2086	.0791	.0322	.1443	.0019	.0979	.7118	.1437	.5430	2.0218

P > .99

(b) WHITE LEGHORNS

Specific gravity	1.058	1.062	1.066	1.070	1.074	1.078	1.082	1.086	1.090	1.094	1.098	1.102	
Fertile eggs observed	2	2	7	18	33	55	186	442	823	520	188	35	2311
Fertile eggs expected	5.16	3.44	7.74	19.78	36.12	82.57	202.12	454.99	799.03	488.54	179.76	31.82	2311.1
χ^2	1.9352	.6028	.0707	.1602	.2695	9.2056	1.2856	.3709	.7191	2.0259	.3777	.3178	17.3410

P > .05

TABLE 4.—ANALYSES OF THE DIFFERENCE IN SPECIFIC GRAVITY BETWEEN FERTILE AND INFERTILE EGGS AND BETWEEN HATCHED AND DEAD GERMS FROM INDIVIDUAL HENS BY THE METHOD OF PAIRED OBSERVATIONS. MEAN DIFFERENCES IN FAVOUR OF FERTILE AND HATCHED IN *(a)* AND *(b)* RESPECTIVELY.

(a) Fertile vs. Infertile

BARRED ROCKS					WHITE LEGHORNS				
No. of hens	Mean difference	t	Necessary t for P of		No. of hens	Mean difference	t	Necessary t for P of	
			.05	.01				.05	.01
80	.00049	1.381	1.960	2.576	74	.00062	2.060	1.960	2.576

(b) Hatched vs. Dead Germs

102	.00418	11.458	1.960	2.576	55	.00336	8.056	1.960	2.576

Although all eggs were carefully candled they were not broken open for examination and there is a possibility that some of the very early deaths were classified as infertiles under the candle. There is also the possibility that some eggs, due to internal quality, are either infertilizable or incapable of developing to the point where fertility can be distinguished. These eggs probably should be classified as deads rather than infertiles as dictated by the physical limitations. Such eggs may be responsible for the results in Table 4 *(a)*.

Specific Gravity and Hatchability

Simple inspection of the data in Table 1 indicates that specific gravity of the fresh egg is a measure of its hatching power. This is confirmed by statistical analyses. For instance, if an χ^2 for goodness of fit is carried out on the proportion of fertile eggs which hatch in the various specific gravity classes, on the assumption that hatchability should be equal in all classes, as was done in the case of fertility in Table 3, the χ^2 value obtained for the Rocks is 47.663 and for the Leghorns 26.742 both being considerably in excess of the .01 error point. Again when the comparison of hatched vs. dead is made for each hen and analysed by "Students" method the t value in both cases greatly exceeds the necessary level for odds of 99 : 1. (See Table 4 *(b)*.)

Further detailed analysis of the data reveal some interesting facts. For instance, the specific gravity of the egg is decidedly an individual hen characteristic, two eggs from the same hen being, on the average, much nearer the same specific gravity than two eggs from different hens. Furthermore, hens laying eggs which are low in specific gravity are generally lower than average in hatchability. For instance, Table 5 shows that of a total of 114 Barred Rocks, 90 laid eggs which averaged higher than the

critical point in specific gravity. These 90 birds averaged 11.6% higher in total eggs hatching than did the remaining 24 which produced eggs averaging lower than the critical point. Nevertheless the few low specific gravity eggs produced by the high birds show much poorer hatchability than those above the critical point from the same birds. Similarly, the few eggs above the critical point produced by the poor birds show a much higher hatchability than those below that point from the same birds. Exactly the same is true of the White Leghorns shown in the same table. In other words, although individual hens can be selected for hatchability by the specific gravity test, there is considerable variability in hatching power between individual eggs from the same hen; this individual egg variability, to a large extent, also can be detected in fresh eggs by the specific gravity test.

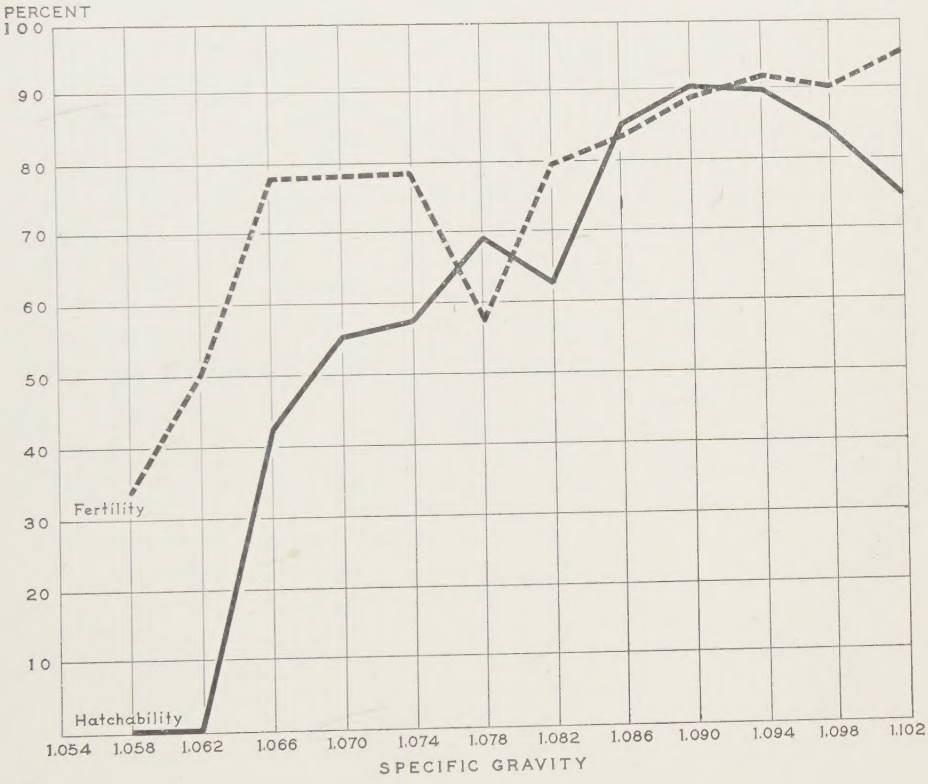

FIGURE 2. Relation of specific gravity of the egg to fertility and hatchability in Leghorns.

Inspection of the data from individual hens shows that when the change from high to low specific gravity, or in other words from high to low quality, or vice versa, occurs, it generally persists for some time. Physiological variability may, however, occur rapidly and the hen may lay eggs which vary in shell quality from day to day. The latter type of variation is the more uncommon type.

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TABLE 5.—A TWO-WAY CLASSIFICATION OF THE DATA, SHOWING (1) HATCHING RECORDS OF HIGH AND LOW SPECIFIC GRAVITY HENS AND (2) HATCHING RECORDS OF HIGH AND LOW EGGS WITHIN EACH CLASS OF HEN.

BARRED ROCKS

	90 hens averaging above critical point				24 hens averaging below critical point			
—	No.	% fertile	% F.H.	% T.H.	No.	% fertile	% F.H.	% T.H.
Good eggs	1971	84.0	85.6	71.8	179	75.4	83.7	81.3
Poor eggs	85	71.8	34.4	24.7	257	79.0	64.0	50.6
Total	2056	83.5	83.7	69.9	436	77.5	71.9	55.7

WHITE LEGHORNS

	82 hens averaging above critical point				18 hens averaging below critical point			
Good eggs	2065	89.2	86.9	77.5	100	80.0	90.0	72.0
Poor eggs	123	91.1	51.8	47.2	228	71.5	64.4	46.1
Total	2188	89.3	84.8	75.7	328	74.1	72.3	54.0

Specific Gravity and Viability

Hatching records were kept on individual eggs in this experiment, but the chicks were pedigreed according to hen and not according to individual egg. That is to say, although a record was kept of the fate of each egg set, and although the chicks which hatched were individually banded, no record was kept to show which particular egg each chick came from. Thus chick mortality cannot be correlated with specific gravity within hens. However, the mortality of the chicks which hatch from high specific gravity hens can be compared with those which hatch from low specific gravity hens.

There were 1,106 Barred Rock chicks from high specific gravity hens placed in the brooders. During the first three weeks of life 28 or 2.53% of these died. Out of 196 chicks from low hens 8 or 4.08% died during the same period. In the Leghorns there were 1,351 chicks from the high hens of which 28 died and 149 from the low hens of which 8 died, giving mortality rates of 2.37 and 4.70% respectively. These give differences of 1.55 and 2.33% in Rocks and Leghorns respectively in favour of the high specific gravity hens.

These figures are not based on samples sufficiently large to provide critical evidence but they do suggest that chicks hatched from low specific gravity eggs may be weaker and show a higher death rate than those from high specific gravity eggs.

DISCUSSION

It is clear from the data presented in this paper that specific gravity differences exist between eggs from different hens as well as between individual eggs from the same hen, and that these differences indicate

hatching power. This means that physiological variability related to hatching power and measurable by specific gravity of the egg exists not only between hens but in the same hen at different times. Since Olsson (1934) has shown that variations in specific gravity are almost entirely due to variations in percentage of shell, the physiological variability which influences hatchability must, in part at least, be concerned with calcium metabolism. Whether the low hatching power of thin and weak shelled eggs is due entirely to the shell, i.e., to inefficient calcium utilization, or whether calcium metabolism is merely one of several physiological processes which when functionally subnormal adversely affects hatchability, remains for future research to disclose. In the former case the shell is a direct indication of hatching power, while if the latter be true the shell can be regarded as a mirror of internal egg quality affecting hatchability. In any case, the proportion of shell on an egg indicates its hatching power, and the salt solution method of testing for this makes the test quite practicable. A pamphlet describing a simple method of putting this test into practice has already been issued by the Poultry Division of the Central Experimental Farm.

The laying hen is one of the most efficient utilizers of calcium in the animal kingdom, since she secretes, during the twenty hours that the shell of a single egg is being formed, approximately 4.2 mg. of calcium carbonate per minute. Such a high rate of calcium utilization requires extreme physiological efficiency. It is not surprising, therefore, that slight deficiencies in certain food factors (e.g., vitamins D, G, and manganese) and slight alterations in environmental conditions such as high temperatures affect calcium metabolism and are almost immediately reflected in weak shelled eggs. For these reasons it is not unreasonable to suppose that the percentage of shell in an egg should reflect the physiological efficiency of the hen at the time the shell of that particular egg was being formed. It is only a step further to suggest that eggs formed during periods of inefficient physiological functioning will be of poor hatching quality.

After the experiments described in this paper were completed, the author's attention was drawn to the work of Mussehl and Halbersleben (1) who measured the effect of specific gravity on fertility, hatchability and growth of chicks. These authors concluded that "There is little correlation between specific gravity, fertility and hatchability of hens' eggs." They found a correlation of .204 between specific gravity and hatchability of fertile eggs, but they state that "the degree of correlation is so slight that it lacks practical usefulness for the poultry producer". On re-examination, their data show no relationship between specific gravity and fertility or between specific gravity and viability of the chick, but hatchability of eggs which are below 1.08 in specific gravity is 16.0% lower than eggs above this point, the respective figures being 39.3 and 55.3. Mussehl and Halbersleben's failure to find a practically useful relationship between specific gravity and hatchability appears to be due to the fact that they attempted to measure this relationship by means of straight line correlation. Their data show the same curvilinear relationship as that shown in this paper (Figures 1 and 2). Furthermore, their estimation of specific gravity was made only to the nearest second decimal by using a commercial device, presumably the "Magic Egg Tester", which was

widely advertised about twenty years ago and for which rather phenomenal claims were made. The author has been able to procure one of these instruments. It is simply a floater upon which the egg is attached, the high specific gravity eggs pulling the floater farther under water than the lower ones. The scale on the floater is very coarse and indefinite and the specific gravity of the eggs can only be determined by properly adjusting for size, large eggs pulling the floater farther under water than small eggs of the same specific gravity. Literature accompanying the instrument shows that the manufacturers claimed the device predicted fertility, hatchability and sex of the chick. These claims undoubtedly were greatly exaggerated and the device was eventually taken off the market.

SUMMARY

Tests based on more than 5000 eggs showed that:—

1. White Leghorn eggs were higher in specific gravity than Barred Rock eggs, the former averaging 1.089 and the latter 1.082. The difference is mainly caused by a higher proportion of shell in the Leghorn eggs.

2. There was a slight tendency for eggs of low specific gravity to be less fertile than those of high specific gravity.

3. A distinct curvilinear relationship was shown between specific gravity of the egg and its hatching power. The Barred Rock eggs decreased rapidly in hatching power below a specific gravity level of 1.074 and White Leghorn eggs did likewise below 1.086.

4. When these two points (i.e., 1.078 for Rocks, 1.086 for Leghorns) were taken as the dividing lines, the low specific gravity eggs averaged 7.8% lower in fertility, 32.4% lower in fertile eggs hatching, and 29.7% lower in total eggs hatching. An average of 22% of the eggs fell below these points, and by discarding these before setting, hatchability of total eggs would be improved 8.3%.

5. Each hen produces eggs with a characteristic specific gravity, but there is considerable variability between eggs from the same hen.

6. Chicks which hatched from low specific gravity hens had a higher death rate during the brooding stage than those from high hens, but there are insufficient data available thus far to prove that this is a true difference. Observations in this connection are continuing.

7. A discussion of the physiological implications of these findings is given.

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PASTURE HUMMOCKS

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One of the most conspicuous features of the surface of old or permanent pastures in Eastern Canada is the presence of mounds or earthy humps covered on the top with dark-coloured mosses or other characteristic plants. These mounds are locally called by different names, as fairy knolls, pasture warts, or nigger heads, but the name *hummock* seems to be as distinctive as any. Although so commonplace that one does not have to go far along any country road to see them, the amount of actual information regarding their nature and their cause of formation is practically negligible. The information which is available seems to be all of the verbal sort, and so conflicting from different sources that one is inclined to believe that no critical observations have yet been made on these interesting phenomena. Since pastureland, once hummocky, is next to worthless for grazing purposes, it is all the more surprising that this phase of investigation has not received more attention.

Many and varied are the explanations offered as to the cause of hummocks. That there is some cause for their formation is shown by the fact that they are not always present on the land from the first, but may develop on smooth or tilled areas which have been neglected. In only a few cases has wooded land been observed with a hummocky surface, and in these cases it might easily be possible for the trees to have invaded and grown up in the hummocky pasture that was there previously.

It is the purpose of this paper to describe several types of hummock formation without offering any final opinion as to their mode of origin. Further critical observations are necessary before this can be done with any degree of assurance.

(1) A hummock may "grow up" around a stone or boulder on or near the surface of the pasture, or perhaps, the boulder may "push up" under the sod due to the force of frost action. In these cases a stone or boulder would be expected to be found beneath the vegetation mat on top of the hummock. This has actually been found the case in some localities (Figure 1), but in the majority of hummocks no trace of a stone can be found.

(2) An ant-hill may be the origin of the hummock (Figure 2). Many mounds, ten inches or more in height and one or two feet wide, are frequently observed being built up by the activity of these insects, probably in their attempt to get away from the too moist consolidated earth below. It is interesting to note that couch grass is invariably found on the surface of hummocks of this nature, even when it is apparently absent in the surrounding pasture. The ant-hill explanation, however, obviously would not appear to hold true for those hummocks, the interior of which shows large pebbles or fragments of rock too large to be carried up to the top of the "hill" by the ants. Figures on the size of the particles making up the hummocks, and also on the maximum loads which can be carried by ants are needed.

FIGURE 1. Hummocks in a pasture at Armdale, Halifax County, Nova Scotia, showing granite boulders protruding from the sides of the moss-covered mounds.

FIGURE 2. An ant-hill (2 others in left background) in a pasture near Lacolle, Que. The height may be judged by the pencil standing at its side.

(3) The hummock may be built up of the remains of plants growing *in situ* year after year and depositing their remains at the base of the stalks. The moss hummocks, so characteristic of southern Quebec and many parts of the Maritime Provinces (Figures 3), have been thought to have developed entirely by this process. The mere mode of growth of the larger acrocarpous mosses, and especially of the hair-cap mosses (*Polytrichum* sp.), being somewhat different from that of true root-bearing plants, is highly con-

ducive to hummock formation. Such mosses continue to grow at the apex, dying off below, with only two or three years' growth remaining alive at the top. When a moss hummock is cut into, the old stems can be readily seen within the upper portion of the body of the hummock. One

FIGURE 3. Moss-hummock in old impoverished pasture in Wolfe Co., Que. The dense growth of hair-cap moss (*Polytrichum* sp.) is readily recognizable on the hummock in the centre foreground. The wire-like plant surrounding the hummock is the moor mat grass or white grass, *Nardus stricta*, the most undesirable of the grasses of hill grazing lands of Europe. This is probably the only record of this grass in Canada.

would expect, then, if moss growth is the only factor operating, that the hummock would be composed entirely, or almost entirely, of the organic material of the plant remains. This, strange to say, is certainly not the case. A considerable proportion of the hummock beneath the living surface mat of moss, and containing embedded moss stems, is inorganic and of a sandy-textured nature. How was this mineral material carried up among the moss stems? There would appear to be no known method by which the stems of the moss could grow downward and bury themselves in the inorganic soil. If the mineral material has actually been brought up, by what agency has it been done?

Frequently plants other than mosses dominate the summit of the hummock. In the Eastern Townships the ubiquitous hardhack branches out from the top of almost every one. Ferns, especially of the genus *Osmunda*, sometimes cover the tops of the hummocks, and in the winter, when their blackened rhizomes lie exposed, give appearances which would

seem to allow them to be appropriately called "nigger-heads". In the Maritimes, ericaceous plants, such as blueberry, lambkill, rhododendron and huckleberry, grow in abundance on the hummocks (Figure 4). The question arises; are such plants to be considered as progenitors of hummock

FIGURE 4. This area along the highway near Parrsboro, N.S. is typical of many of the old abandoned or run-down pastures in this region. The low, rounded hummocks are conspicuous with their covering of low woody heath plants which are avoided by all grazing stock. Although the total surface area of the pasture is greatly increased by the mounds, the grazable area is reduced to only the small patches between the hummocks. Spruce trees are colonizing here, also.

FIGURE 5. These are not earth hummocks but merely the dense cushion-like growth of the heath plant, *Corema Conradii*, growing on the sterile sandy soil at Middleton, N.S. Each mound represents a single plant of several years' growth. The leaves are thick, dark green, and persistent.

formation, or merely opportunists taking advantage of the particular edaphic conditions provided by the already formed mound?

This aspect of hummock formation should not be confused with the "tussocks" formed by many species of plants. The nefarious flying bent grass of the hill grazings of Wales and Scotland is a plant of this nature.

FIGURE 6. Trample hummocks in moist pasture land. These hummocks near Hemmingford, Que., are from 1 to 1½ feet in height, and are closely placed throughout the moister portions of this pasture. Where the land is better drained, as along the fence, their absence is noticed. The soil of the pasture including the hummocks is black and muck-like.

Other tufted plants, sedges and rushes in wet land, *Corema* in the sandy barrens of Nova Scotia (Figure 5), or hawthorns and spruce dwarfed by browsing, give the appearance of hummocks, but are entirely made up of living or dead plant tissues.

(4) Hummocks might possibly be built up by the reaction that plants have on their environment by affecting the processes of erosion and deposition. A firmly-rooted plant growing on loosely packed soil, as we find in sandy exposed areas, could easily obstruct the wind and cause it to deposit drifting particles of soil that it might be carrying. This would tend to build up a mound behind or around the plant tuft. In other situations, a strongly-rooted plant would prevent the wearing or washing away of soil immediately at its base by the eroding agencies of strong wind or flowing water. This would tend to leave the plant resting on top of a mass of soil which would be very hummock-like.

(5) Mechanical disturbances may also contribute to hummock formation. The trampling of livestock when the land is wet and spongy in spring or after heavy rains, or the heaving of the soil by the agency of ice formation, undoubtedly are important factors to be considered. The "trample hummocks" of poorly drained land will provide good examples of this type (Figure 6.) The throwing up of clods of earth on the removal of stumps, by excavations for post holes, as well as by burrowing animals,

may provide the excuse for a hummock to form. Ridges or terraced-paths seen on the sloping ground in pastures are in a sense elongated hummocks, and are formed by a solifluxion caused by some mechanical process. Well-formed hummocks, however, may be found on the tops of hills and in other locations which should be well-drained (Figure 7), and explanations as to their formation cannot be offered as yet.

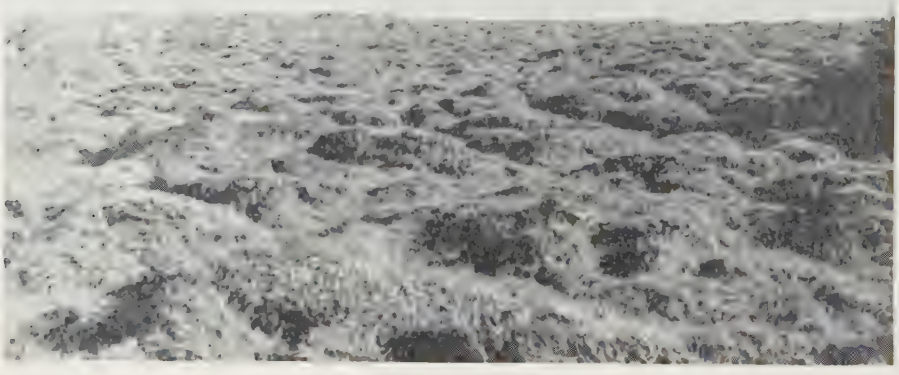

FIGURE 7. Numerous low hummocks in exposed pasture on headland overlooking the sea near Lawrencetown, Halifax Co., N.S. The pasture slopes up to the horizon in this picture which is the edge of the high eroding cliff.

FIGURE 8

A. General view of a hummocky pasture near Ottawa, Ont. The area in the immediate foreground is improperly drained and is covered with rushes and sedges and coarse-growing plants. The sward on the better-drained parts is poor. The soil is a light sand.

B. This section through one of the hummocks shows the layer of mosses growing on the top, then the dark-coloured layer. The whole interior of the base of the hummock is composed of highly leached, loose structured, soil.

CONCLUSION

Observations made so far have not been extensive or intensive enough to provide definite information on which to base conclusions as to the cause and mode of formation of pasture hummocks. It is apparent that there are different types which develop under particular conditions and in different situations, and the problems associated with their development and distribution are somewhat complex. Any information based on the experience or personal observation of workers would be welcomed by the author.

An interesting problem centres around the differences in the species of plants which grow on the tops, sides, and around the base of the hummocks. The zonation which exists is undoubtedly due to the different environmental factors which operate in each section of the micro-habitat. The top of the hummock is more exposed to the drying effect of the wind, and xerophytic species might be expected to be found there. There are certainly wider variations in temperature and moisture and a greater degree of aeration and leaching of soluble elements than in the soil at the base. Accurate measurements to determine the extent and variation in daily temperature, water content, texture, chemical composition, reaction, etc. of the soil within the hummock are yet to be made (Figure 8).

Although the presence of a large number of hummocks increases the surface area of the pasture considerably, the additional surface is inhabitated by plants of a type so coarse, unproductive and unpalatable that it is rendered useless for grazing purposes. The hummock, furthermore, provides an opportunity for weeds, shrubs and trees to get a foothold, and it is only a matter of time until the land is in trees and beyond easy reclamation. The prevention of the formation of hummocks, and their destruction when once formed are important problems in the management of such lands. The methods by which hummocky pastures may be renovated or improved do not seem to be clearly stated nor widely practised.

ACKNOWLEDGMENT

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APPLE WAXING EXPERIMENTS[1]

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INTRODUCTION

The experiments herein reported were initiated in 1936 at the request of, and in co-operation with, a commercial company. The activities of this company in the commercial application of waxes to citrus fruit in California were extended to the State of Washington where an experimental laboratory was set up to study the application of wax emulsions to apples. Preliminary work proved encouraging with the Delicious, Jonathan, Rome Beauty and Winesap varieties. Among the advantages claimed by the company for waxed fruit were increased firmness and crispness after storage, and decreased shrinkage in the fruit after removal from cold storage to room temperature. The company reported that scald, Jonathan spot and rots were also controlled to some degree. In order to ascertain the influence of wax emulsions on Okanagan grown apples, experiments were undertaken by the Summerland Experimental Station.

REVIEW OF LITERATURE

Experiments involving the application of waxes, oils and emulsions of these substances to apples have been reported by several investigators. Magness and Diehl (5) using oil and paraffin coatings showed that these substances reduced the permeability of the epidermis, rate of respiration, rate of softening, and delayed the change of skin colour from green to yellow. Such retardation in rate of ripening was at the expense of flavour unless the coatings were very light. Coatings so light as not to injure the flavour of the fruit caused only a very slight retardation in the softening process. Even very thin coatings resulted in bad flavour in certain varieties, particularly when such varieties were exposed to high temperatures.

Smock (7) using commercial wax preparations of unspecified composition on apples and pears held at 65° F., found a marked reduction in respiration rate of the treated fruit accompanied by a striking increase in carbon dioxide in the internal atmosphere of the fruit. Rate of ripening was also retarded. However, when waxes were applied in sufficient quantity to retard ripening materially, abnormal flavours resulted.

Hitz and Haut (3) studied the effect of several commercial wax emulsions on Golden Delicious and Grimes Golden apples held in cold storage. Throughout their experiments they found that waxing reduced the percentage of wilting. Waxing immediately after picking induced scald and abnormal flavours, but after a delayed storage period of one week at 57 to 60° F. fruit thus treated showed decreased wastage in comparison with

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untreated fruits placed in cold storage immediately after picking. Such differences in shrinkage as were obtained in favour of waxing were relatively slight, the reduction in shrinkage being roughly of the order of 1%.

Claypool (2) conducted waxing experiments with pears, plums, nectarines and peaches. A comparison of waxed and unwaxed fruits showed not only a marked difference between effects of different wax concentrations but also wide variations in the effectiveness of different waxes. He found that the most effective wax for protecting one kind of fruit might not be the most effective for another. Furthermore, he found that waxes materially increased percentage of decay.

Experiments on waxing tomatoes by Brooks (1) and on miscellaneous vegetables by Platenius (6) have shown promising practical results in reducing moisture loss. Platenius found that emulsions containing 7% solids were generally adequate. He recommended the commercial application of waxes to topped carrots and to cucumbers, and noted that the response of root crops to waxing was usually favourable.

In most waxing experiments, emphasis has been laid upon the beneficial effect of waxes upon reduction in shrinkage. Shrinkage of fruit is related principally to two factors: the amount of cuticular covering or natural wax on the epidermis, and the saturation deficit of the atmosphere.

The amount of cuticular covering on fruits varies widely. On apples and cherries it is fairly abundant, while on fruits such as apricots and peaches, it is less plentiful. Moreover, the amount of natural wax varies widely with different varieties of apples. Thus Winesap and Ben Davis develop a heavy coating of wax while McIntosh and Golden Delicious develop a light coating. The more natural wax there is on the skin of an apple the greater is the tendency to check water loss.

The saturation deficit of the atmosphere is a factor of great importance in regulating the water loss from stored fruit. The saturation deficit is an accurate expression of vapour pressure gradients under given conditions of temperature and humidity. The relation of saturation deficit to transpiration in plants is discussed by Meyer and Anderson (4). In view of the important influence of atmospheric humidity on shrinkage of apples in storage the concept of saturation deficit is discussed at some length in the following paragraphs.

Relative humidity expresses the moisture content of the air as a percentage of the amount that would be present if the air were saturated at the same temperature. The saturation deficit is based upon the partial pressure exerted upon the atmosphere by the water vapour content of the atmosphere. At equilibrium at any given temperature, the vapour pressure of water is equal to the partial pressure exerted upon the atmosphere by the water vapour present in the atmosphere. The saturation deficit is therefore calculated from the difference between the partial pressure exerted by water vapour in the air at a given relative humidity and temperature, and that of saturated air at the same temperature. It is an expression of the activity of water molecules in the air under given conditions of temperature and humidity. With a given relative humidity, the saturation deficit increases with each progressive rise in temperature. This

fact is illustrated in Table 1, saturation deficit being expressed in terms of millimetres of mercury.

Thus with relative humidity of 80% at 41° F., the saturation deficit of the air is 1.31 millimetres of mercury, while with the same humidity at a temperature of 32° F. the saturation deficit is 0.92 millimetres of mercury or only 70% as great as at the higher temperature. Assuming

TABLE 1.—SATURATION DEFICIT OF THE ATMOSPHERE UNDER GIVEN CONDITIONS OF TEMPERATURE AND HUMIDITY

Temperature	Relative humidity	Partial pressure exerted by water vapour in saturated air	Partial pressure exerted by water vapour in unsaturated air	Saturation deficit
°F.	%	mm. Hg	mm. Hg	mm. Hg
32	40	4.58	1.83	2.75
32	80	4.58	3.66	.92
41	40	6.54	2.62	3.92
41	80	6.54	5.23	1.31
68	40	17.54	7.02	10.52
68	80	17.54	14.03	3.51
86	40	31.82	12.73	19.09
86	80	31.82	25.46	6.36

that the intercellular spaces of an apple contain air practically 100% saturated with water vapour, the above data indicate that under a relative humidity of 80% there would be only 70% as great a tendency for water vapour to evaporate from the fruit into the air at 32° F. as at 41° F. Similarly it may be seen from Table 1 that at a temperature of 41° F. and a relative humidity of 40%, the saturation deficit of the air is 3.92 millimetres of mercury, while at a temperature of 86° F. and a relative humidity of 80%, it is 6.36 millimetres of mercury or 1.62 times as great. Saturation deficit of the air is therefore a more accurate expression of vapour pressure gradients in shrinkage experiments with fruits than is the concept of relative humidity.

PROCEDURE

Waxing experiments were conducted in the seasons of 1936–37, 1937–38, and 1939–40. The wax ingredients used consisted principally of carnauba and paraffin (M.P. 130°) plus an emulsifier. In the first two seasons the emulsifier used was triethanolamine, and in the 1939–40 season a sodium soap formed from the interaction of oleic acid and sodium hydroxide. Various strength emulsions between 3 and 6% were used. The emulsion was applied by dipping the fruit into a warm emulsion at a temperature of 105° F. and then drying it on newspapers. The fruit was waxed within 2 days of picking, and was wrapped and placed in cold storage within 24 hours of time of waxing. The cold storage temperature used in these experiments was uniformly 32° F., and the temperature of the ripening room was maintained at about 65° F. Relative humidity at both temperatures was maintained at various levels from 30 to 90%. The saturation deficit of the atmosphere for each temperature-humidity combination was

calculated in terms of millimetres of mercury. This provides an accurate indication of the relative pull of the storage atmosphere on the moisture content of the fruit.

RESULTS

Shrinkage of Apples in Cold Storage Ripening Rooms

To secure information regarding the shrinkage of apples under customary cold storage conditions sample boxes of unwaxed McIntosh were weighed at the beginning and close of the storage period. The results are presented in Table 2.

TABLE 2.—LOSS IN WEIGHT PER 40-POUND BOX OF MCINTOSH, COLD STORED AT 32° F. AND RELATIVE HUMIDITY OF 85 (SATURATION DEFICIT 0.68 MM. MERCURY) FROM OCTOBER 2 TO MAY 17

Lot No.	Loss of weight	Lot No.	Loss of weight
	lb.		lb.
1 Unwashed	1.15	5 Unwashed	1.06
2 Unwashed	0.84	6 Unwashed	1.04
3 Unwashed	0.76	7 Washed	0.98
4 Unwashed	0.60		

These data suggest that for the McIntosh variety actual shrinkage over a period of $7\frac{1}{2}$ months of commercial storage is about 1 pound per 40-pound box or $2\frac{1}{2}\%$.

Similar samples of these same lots of apples were removed from 32° F. storage on October 29 to a ripening room held at 60° F. with a relative humidity of 85 and held there until December 4. Their weight losses during this period are shown in Table 3.

TABLE 3.—SHRINKAGE PER 40-POUND BOX OF MCINTOSH, STORED AT 32° F. FOR FOUR WEEKS, AND THEN REMOVED TO A TEMPERATURE OF 60° F. AND RELATIVE HUMIDITY OF 85 (SATURATION DEFICIT 1.97 MM. MERCURY) FROM OCTOBER 29 TO DECEMBER 4

Lot No.	Loss of weight	Lot No.	Loss of weight
	lb.		lb.
1	0.55	4	0.50
2	0.35	5	0.40
3	0.35	6	0.65

The data presented in Table 3 indicate that fruit held in the ripening room for 5 weeks with a relative humidity of 85% lost only about $\frac{1}{2}$ pound in weight per 40-pound box. The data contained in Tables 2 and 3 indicate that without waxing moisture losses from fruit stored in humid atmospheres are very small.

Effect of Waxing and Atmospheric Humidity upon Shrinkage

A study was made of the shrinkage of both waxed and unwaxed fruit of the McIntosh and Delicious varieties. The fruit was of the Extra Fancy grade, and was divided into four lots for treatment. The first three treatments consisted of dipping the fruit into 3, 4, and 5% wax emulsions respectively, and the fourth treatment represented the check unwaxed fruit. The apples were waxed and stored at 32° F. within 48 hours of picking. On December 17 this fruit was removed from storage and two 1500-gram samples of each lot were placed in a ripening room held at a temperature of 70° F., one at a humidity of 90% and the other at a humidity of 30%. The fruit was weighed again on January 12 and the amount of shrinkage determined. The data are given in Table 4.

TABLE 4.—INFLUENCE OF RELATIVE HUMIDITY ON LOSS OF WEIGHT OF WAXED AND UNWAXED FRUIT HELD AT 70° F. (DECEMBER 17 TO JANUARY 12 INCLUSIVE)

Treatment	Percentage loss of weight		Ratio high to low humidity
	Low humidity (about 30%)	High humidity (about 90%)	
	Saturation deficit 13.01 mm. Hg	Saturation deficit 1.86 mm. Hg	
McIntosh			
3% wax emulsion	8.27	2.52	3.28 : 1
4% wax emulsion	8.52	2.57	3.31 : 1
5% wax emulsion	7.83	2.09	3.75 : 1
Check	12.16	3.12	3.89 : 1
Average for three wax treatments	8.21	2.39	
Shrinkage ratio, wax : check	1 : 1.48	1 : 1.30	
Delicious			
3% wax emulsion	7.47	3.07	2.43 : 1
4% wax emulsion	7.94	2.65	3.00 : 1
5% wax emulsion	7.02	2.33	3.01 : 1
Check	10.36	2.76	3.75 : 1
Average for three wax treatments	7.48	2.68	
Shrinkage ratio, wax : check	1 : 1.38	1 : 1.03	

The above data indicate that under conditions of low atmospheric humidity waxing the fruit resulted in a marked reduction in shrinkage, which was practically the same with all three wax concentrations. In the case of McIntosh the shrinkage ratio of waxed to unwaxed fruit amounted to 1 : 1.48, and in the case of Delicious to 1 : 1.38. Under high humidity the reduction in shrinkage was much less marked particularly with the Delicious variety where the effect of the high humidity practically cancelled the effect of the wax. These results suggest that where the fruit is liable to be held under conditions of low humidity, as in a grocery store or in the home, waxing might materially aid in reducing moisture loss.

However, the effect of the humidity (saturation deficit) of the atmosphere was much greater on shrinkage of apples than was waxing. Thus McIntosh apples both waxed and unwaxed, and held under low humidity,

lost about 3.5 times as much weight as similar apples under high humidity, and Delicious about three times as much. In interpreting the results of waxing experiments, the importance of the atmospheric humidity cannot be over-emphasized.

In another season the ratio of shrinkage losses in waxed and unwaxed fruit was studied for a number of different varieties using a 6% wax emulsion. The losses in weight were determined with fruit removed from cold storage to a ripening room held at a temperature of 60° F. and a relative humidity of 85.

The data are presented in Table 5.

TABLE 5.—INFLUENCE OF 6% WAX ON FRUIT SHRINKAGE AFTER REMOVAL FROM 32° F. TO 60° F. RIPENING ROOM (RELATIVE HUMIDITY 85, SATURATION DEFICIT 1.97 MM. HG.)

Variety	Date removed from cold storage	Length of run	Loss of weight per day		Weight loss ratio of waxed to unwaxed
			Waxed	Unwaxed	
	1937	days	%	%	
McIntosh	Jan. 12	20	.120	.214	1 : 1.79
	Feb. 1	14	.120	.186	1 : 1.56
	Feb. 1	14	.122	.204	1 : 1.67
Average			.121	.201	1 : 1.67
Jonathan	Jan. 12	29	.083	.143	1 : 1.73
	Jan. 27	61	.073	.116	1 : 1.58
Average			.078	.130	1 : 1.65
Delicious	Jan. 25	21	.082	.137	1 : 1.67
	Feb. 11	14	.043	.093	1 : 2.17
	Feb. 15	42	.058	.096	1 : 1.67
	Feb. 15	42	.056	.092	1 : 1.65
Average			.060	.104	1 : 1.79
Newtown	Feb. 12	47	.068	.087	1 : 1.26
	Feb. 12	47	.074	.083	1 : 1.12
Average			.071	.085	1 : 1.19
Rome Beauty	Feb. 19	40	.061	.087	1 : 1.43
Wagener	Feb. 17	41	.051	.094	1 : 1.86
Stayman	Feb. 17	41	.061	.089	1 : 1.46
Winesap	Feb. 15	43	.093	.115	1 : 1.23
Average of all lots of all varieties			.078	.122	1 : 1.59

In Table 5 the loss of weight per day is shown for waxed fruit and for unwaxed fruit. The ratio of loss of weight of one to the other is indicated. For each variety an average ratio has been worked out. It will be noted that the McIntosh variety lost the most weight. With all varieties tested the waxed apples lost weight less rapidly than the unwaxed apples. The difference in loss of weight between waxed and unwaxed apples was much greater with McIntosh, Jonathan and Delicious than with Newtown and Winesap. This was probably due to differences in the amount of natural

wax secreted by the skins of these varieties. Taking the average of all lots of all varieties tested the unwaxed apples lost 59% more weight than the waxed apples. However, the actual shrinkage was not great, calculated on the basis of a 40-pound box of fruit. Unwaxed McIntosh lost weight at the rate of 1 pound in 12 days as compared with 1 pound in 21 days for waxed McIntosh. Newtown lost weight at the rate of 1 pound in 29 days for unwaxed fruit and 1 pound in 35 days for waxed fruit per 40-pound box. In this connection, however, it should be noted that the fruit was kept in a moist atmosphere. Under drier air conditions, the shrinkage would likely be considerably greater and might have commercial significance.

The Effect of Waxing upon Respiration

Respiration determinations were made with 8 varieties which had been dipped in a 6% wax emulsion. This fruit was held at 32° F. until January or February, removed to a temperature of 60° with 85 relative humidity, and 5 kilogram samples weighed out for the respiration experiments. A number of determinations were made with each variety. Sample data are presented in Table 6. These determinations showed a small, but fairly consistent decrease in rate of respiration with waxed as compared with unwaxed fruit. The average decrease in respiration rate for all varieties amounted to 13.8%.

TABLE 6.—EFFECT OF WAXING ON APPLE RESPIRATION (FRUIT STORED IMMEDIATELY AFTER PICKING AT 32° F. AND REMOVED TO RIPENING ROOM AT 60° F. AND RELATIVE HUMIDITY OF 85)

Variety	Date removed from storage	Date of runs	Length of runs	Carbon dioxide respired per kilogram of fruit per hour	
				Waxed	Unwaxed
			hours	cc.	cc.
McIntosh	Jan. 12	Jan. 14	4.83	5.66	5.82
		Jan. 25	5.42	2.60	3.10
Jonathan	Jan. 28	Jan. 29	6.00	3.22	3.76
		Feb. 5	5.92	3.64	4.12
		Feb. 23	6.16	2.90	2.90
Delicious	Jan. 25	Jan. 26	5.00	1.86	2.44
		Feb. 5	5.75	3.06	4.14
		Feb. 16	5.83	3.20	3.62
		Feb. 17	4.75	3.16	3.80
		Mar. 2	6.20	3.28	3.84

The Effect of Waxing upon Keeping Quality

In its effect upon keeping quality waxing has produced several interesting results. Studies have been made with McIntosh and Delicious for three years and with Jonathan for two years. All data recorded are for fruit stored in plain wraps. The data are not entirely consistent from year to year. This may be due to slight changes in the composition of the wax or to the effect of seasonal weather conditions on the fruit. The information secured is summarized in Table 7.

Delicious: Waxing produced no significant effect upon softening of Delicious. On the other hand in two years out of three wax emulsions of a concentration of 5 or 6% markedly delayed the onset of mealiness and aldehydic flavour in this variety, and increased its storage life. Wax emulsions of 3 or 4% used in 1937 were not effective in delaying mealiness. Furthermore, waxing induced a type of scald which was not observed on the checks. Whether or not this type of scald can be controlled by oil

TABLE 7.—EFFECT OF WAX EMULSIONS UPON KEEPING QUALITY OF FRUIT STORED AT 32° F. AND THEN REMOVED TO RIPENING ROOM AT 60° F.

Variety	Wax concentration	Date removed from cold storage to ripening room	Firmness when removed	Period of good eating condition	Mealiness, end of three weeks	Flavour	Scald	Coreflush
	%		lb.	days			%	%
Delicious 1936	6	Feb. 11	14.5	37	Excessive	Good	46	—
	Check		14.5	15	None	Good	9	—
Delicious 1937	3	Mar. 23	14.9	10	Excessive	Poor	68	—
	4		15.3	10	Moderate	Fair	67	—
	5		15.8	20	Moderate	Fair	47	—
	Check		14.7	8	Excessive	Poor	3	—
Delicious 1939	5	Feb. 12	12.8	20	This season fruit did not go mealy	Fair	0	—
	Check		12.4	20		Fair	0	—
McIntosh 1936	6	Feb. 1	11.4	7	—	Fair	0	10
	Check		11.7	7	—	Fair	0	22
McIntosh 1937	3	Mar. 23	12.3	22	—	Fair	20	2
	4		12.2	35	—	Fair	40	4
	5		12.2	35	—	Fair	17	2
	Check		11.7	10	—	Fair	0	53
McIntosh 1939	5	Jan. 26	10.0	21	—	Good	0	20
	Check		9.8	21	—	Good	0	42
						Jonathan		Spot
Jonathan 1936	6	Jan. 27	—	39	—	Good	17	—
	Check		—	39	—	Good	57	—
Jonathan 1939	5	Feb. 10	—	21	—	Fair	19	—
	Check		—	21	—	Fair	56	—

wraps has yet to be determined. In the 1939 season waxed fruit was oil wrapped. However the 1939 crop proved remarkably scald-free, and no scald developed on either waxed or unwaxed Delicious. It may be that the absence of scald on the waxed Delicious was due to a slight change in composition of the wax. Flavour of waxed fruit was, as a rule, equal to that of control lots.

McIntosh: Waxing did not retard the softening of McIntosh in cold storage. On the other hand, in one season (1937) waxing with 4 or 5% emulsions markedly prolonged the storage life of this variety as compared with a 3% emulsion and checks. Fruit receiving a 4 or 5% emulsion

remained in good eating condition for 35 days while untreated fruit was overripe after ten days. However in the same season (1937) there was a marked development of a type of scald on the waxed fruit. Further experiments will be required to determine whether this form of scald can be controlled by oiled wraps.

With the McIntosh variety marked control of coreflush has been secured by the use of wax emulsions. In 1936 and 1938 this disorder was reduced by 50% and in 1937 practically eliminated.

Jonathan: In experiments conducted in 1936 as well as in 1939 it was found that waxed fruit developed significantly less Jonathan spot than unwaxed fruit. In fact there was three times as much Jonathan spot on the unwaxed fruit as there was on the waxed. As far as keeping quality of the fruit was concerned no differences were detected between waxed and unwaxed apples. Waxing did not harm the flavour of the fruit.

Other Varieties: Waxing experiments using a 6% emulsion have also been carried out with Winesap, Stayman, Newtown, Wagener and Rome Beauty, without any significant effects being noted except a tendency to control coreflush in Newtowns and a slight scald injury on Stayman and Winesap.

SUMMARY

1. The importance of the saturation deficit of the atmosphere to evaporation of water from fruits is discussed.

2. The procedure followed in waxing experiments conducted with Delicious, McIntosh, Jonathan, Rome Beauty, Stayman and Winesap apples over a three-year period is outlined.

3. Actual shrinkage of fruit under commercial cold storage conditions of 7½ months was found to be about 1 pound per bushel, and shrinkage during a 5-week period in a humid ripening room held at 60° F. was about ½ pound per bushel.

4. Waxing materially reduced the shrinkage of apples held at room temperature under conditions of low humidity, but under conditions of high humidity there was little difference in the shrinkage of waxed and unwaxed fruit. In fact the humidity of the atmosphere was a more potent factor than waxing in regulating loss of moisture from the fruit.

5. Waxing reduced respiration intensity of apples by about 14% on the average.

6. Waxing in some seasons markedly prolonged the saleable period of McIntosh and Delicious apples after removal from cold storage to the ripening room.

7. Waxing delayed the onset of mealiness in Delicious, reduced coreflush in McIntosh and reduced Jonathan spot on Jonathan.

8. The wax used induced a form of scald on McIntosh and Delicious. It has not been determined whether this type of scald can be controlled by oiled wraps.

9. The flavour of varieties treated was not appreciably affected by waxing.

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VARIATION OF MOISTURE CONTENT OF HONEY WITHIN THE SUPERS[1]

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Studies on the variation of the amount of water in nectar have been conducted by different investigators. Park (5) has examined the nectar from practically all honey plants of Iowa, and has found them to contain as high as 60% of water. The concentration of the nectar is influenced by various factors as is shown by Park (6), Vansell (9), Munro (4), Pellett (8), and others. Therefore, variations might be expected of the product when it is collected by the bees and stored in the hive. However, the manipulation of the "honey-nectar" before it is stored in the cells, the processes of evaporation as described by Park (7) and, finally, the filling of the cells with honey collected over a period of time would mask any effect caused by factors influencing the concentration of the nectar before it was gathered.

Further ripening occurs from the exposed surfaces and even from capped honey when the relative humidity is below a certain point. Martin (3) has shown that honey containing between 17 and 18% of moisture is at an equilibrium when the relative humidity is at 58%, so that evaporation occurs from unripened honey whenever the relative humidity is below this point.

It has been found (10) that honey from uncapped cells often contains less moisture than that from capped cells in the same comb. However, there appears to be great variation between the various sections of comb and even between adjacent cells.

Consequent study was made on three supers of normally capped honey and the data obtained were analysed statistically to determine if any significant differences occurred in the moisture content of honey from different parts of the comb.

EXPERIMENTAL MATERIAL AND PROCEDURE

Three supers were chosen at random from hives situated in different locations in the Central Experimental Farm Apiary. One of these, No. 202 was from a hive facing West, while the other two, Nos. 324 and 336, were from hives facing South. All supers were taken at extracting time and were normally capped, i.e., the combs were more than two-thirds capped. For purposes of designation, frames were numbered from left to right as the observer faced the same way as the hive; end 1 refers to the end of the frame towards the front of the hive; and the two sides of the frame bear the designation of the direction in which they were facing. Frames were arbitrarily divided into 9 parts on each side and readings were taken on a

[1] Contribution from the Bee Division, Experimental Farms Service, Dominion Department of Agriculture, Ottawa, Canada.

[2] Graduate Assistant.

sample of honey from each part. The divisions vertically (Verticals) were identified as top, centre, bottom, and those horizontally (Horizontals) as end 1, middle, and end 2. Data in detail are presented in the appendix.

Readings on the honey samples were made by the refractometer, the instrument used being of the Zeiss Industrial type. The temperature of the prisms was controlled at 20° C. by running water. The conversion tables of Chataway (2) were used. It became necessary to extrapolate these tables for the readings of higher moisture. Check duplicate and triplicate readings were made on each sample.

In taking the samples of honey a teaspoon was dug into the comb, to the bottom of the cells. In this way honey was obtained from several cells in each part of the comb. It was thought at first that conclusions might not be justifiably based on one sample from each part, so in preliminary work three samples were taken from each part and the data analysed statistically.

RESULTS

Analysis of variance revealed no significant difference between replicate samples of honey from the arbitrarily chosen areas of the combs. In fact replicates came so far from indicating significance that one was justified in taking any one reading on a particular part as being representative of that area.

The percentages of moisture in the honey taken from different locations in the combs are presented in Appendix Tables 1, 2, and 3. These data were analysed by the variance method and the results are shown in Text Tables 1, 4, and 8.

TABLE 1.—ANALYSIS OF VARIANCE OF THE MOISTURE CONTENT OF HONEY FROM DIFFERENT PARTS OF A NORMALLY CAPPED SUPER

(Super No. 202)

Variance due to	*D.F.*	*S.S.*	*M.S.*	*F.*	*F.* (*P* = .05)
Sides	1	2.82691	2.82691	3.53	3.94
Horizontals	2	2.47940	1.23970	1.55	3.09
Verticals	2	8.36820	4.18410	5.23	3.09
Frames	8	268.50308	33.56289	41.94	2.03
Sides × Horizontals	2	0.70458	0.35229	–	–
Sides × Verticals	2	1.28985	0.64493	–	–
Sides × Frames	8	46.50755	7.56344	9.45	2.03
Horizontals × Verticals	4	1.29327	0.32332	–	–
Horizontals × Frames	16	85.39172	5.33698	6.67	1.75
Verticals × Frames	16	35.20292	2.20018	2.75	1.75
Error (Sides × Horizontals × Verticals × Frames)	98*	78.41672	0.80017	–	–
Total	161	530.98420	–	–	–

* 2 *D.F.* lost in filling missing readings.

It may be seen in Table 1 that there was no significant difference between the moisture content in honey collected from different sides or from horizontal positions.

Vertical Positions

There were high significant differences in the moisture of the honey taken from the vertical positions in the comb. This is summarized in Table 2.

TABLE 2.—MEAN PERCENTAGE MOISTURE IN HONEY FROM VERTICAL POSITIONS

Positions	Moisture
	%
Top	17.3722
Centre	17.4944
Bottom	17.9037
Necessary difference for significance (P = .05)	0.3374

Frames

There were very high significant differences between the moisture content of honey from different frames. Results are summarized in Table 3.

TABLE 3.—MEAN PERCENTAGE MOISTURE IN HONEY FROM DIFFERENT FRAMES

Frame No.	Moisture
	%
1	21.0833
2	17.1222
3	17.4444
4	17.7056
5	17.3833
6	17.2944
7	16.3444
8	16.9389
9	16.9944
Necessary difference for significance (P = .05)	0.5844

Results of the analysis of data presented in Appendix Table 2 are given in Table 4.

TABLE 4.—ANALYSIS OF VARIANCE OF THE MOISTURE CONTENT OF HONEY FROM DIFFERENT PARTS OF A NORMALLY CAPPED SUPER

(Super No. 336)

Variance due to	*D.F.*	*S.S.*	*M.S.*	*F.*	*F.* (P = .05)
Sides	1	0.19358	0.19358	–	–
Horizontals	2	21.80333	10.90167	16.64	3.09
Verticals	2	8.72445	4.36223	6.66	3.09
Frames	8	84.06445	10.50806	16.04	2.03
Sides × Horizontals	2	1.47272	0.73636	1.12	3.09
Sides × Verticals	2	2.82419	1.41209	2.16	3.09
Sides × Frames	8	20.01753	2.50219	3.82	2.03
Horizontals × Verticals	4	22.74555	5.68639	8.68	2.46
Horizontals × Frames	16	39.50222	2.46889	3.77	1.75
Verticals × Frames	16	10.44777	0.65299	–	–
Error (Sides × Horizontals × Verticals × Frames)	100	65.52421	0.65524	–	–
Total	161	277.32000	–	–	–

It may be seen that no significant difference was apparent between sides.

Horizontal Positions

The differences between the moisture content of honey from horizontal positions were very highly significant. The means are presented in Table 5.

TABLE 5.—MEAN PERCENTAGE MOISTURE IN HONEY FROM HORIZONTAL POSITIONS

Positions	Moisture
	%
End 1	16.6611
Middle	17.5389
End 2	16.9333
Necessary difference for significance (P = .05)	0.3053

Vertical Positions

High significant differences appeared between the moisture content of honey from the vertical positions in the comb. Table 6 contains a summary of the results.

TABLE 6.—MEAN PERCENTAGE MOISTURE IN HONEY FROM VERTICAL POSITIONS

Positions	Moisture
	%
Top	16.8481
Centre	16.9148
Bottom	17.3704
Necessary difference for significance (P = .05)	0.3053

Frames

Honey from the different frames of this super showed high significant differences in moisture content. The differences can be seen from Table 7.

TABLE 7.—MEAN PERCENTAGE MOISTURE IN HONEY FROM DIFFERENT FRAMES

Frame No.	Moisture
	%
1	18.1444
2	16.0722
3	16.4444
4	16.8333
5	17.1167
6	17.0944
7	16.9778
8	18.3333
9	16.3833
Necessary difference for significance (P = .05)	0.5288

Data presented in Appendix Table 3 give analytical results which appear in Table 8.

TABLE 8.—ANALYSIS OF VARIANCE OF THE MOISTURE CONTENT OF HONEY FROM DIFFERENT PARTS OF A NORMALLY CAPPED SUPER

(Super No. 324)

Variance due to	*D.F.*	*S.S.*	*M.S.*	*F.*	*F.* ($P = .05$)
Sides	1	2.72222	2.72222	3.11	3.94
Horizontals	2	24.19704	12.09852	13.82	3.09
Verticals	2	130.51815	65.25408	74.55	3.09
Frames	8	201.64445	25.20556	28.80	2.03
Sides × Horizontals	2	0.75704	0.37852	—	–
Sides × Verticals	2	2.26778	1.13389	1.30	3.09
Sides × Frames	8	19.73777	2.46722	2.82	2.03
Horizontals × Verticals	4	11.00148	2.75037	3.14	2.46
Horizontals × Frames	16	6.87963	0.42998	–	–
Verticals × Frames	16	27.56018	1.72251	1.97	1.75
Error (Sides × Horizontals × Verticals × Frames)	100	87.53204	0.87532	–	–
Total	161	514.81778	–	–	–

It is obvious from Table 8 that no significance exists in the case of the honey from different sides.

Horizontal Positions

A very high significant difference is found to occur between the moisture content of honey from different horizontal positions in the combs of this super. A summary appears in Table 9.

TABLE 9.—MEAN PERCENTAGE MOISTURE IN HONEY FROM HORIZONTAL POSITIONS

Positions	Moisture
	%
End 1	17.0074
Middle	17.3593
End 2	16.4222
Necessary difference for significance ($P = .05$)	0.3529

Verticals

Here exceptionally high significant differences appeared between moisture content of the honey from the vertical positions. Table 10 presents the summarized results.

TABLE 10.—MEAN PERCENTAGE MOISTURE IN HONEY FROM VERTICAL POSITIONS

Positions	Moisture
	%
Top	16.0315
Centre	16.6018
Bottom	18.1556
Necessary difference for significance ($P = .05$)	0 3529

Frames

There were high significant differences between the moisture content of honey from the different frames of this super as appears from the summary presented in Table 11.

TABLE 11.—MEAN PERCENTAGE MOISTURE IN HONEY FROM DIFFERENT FRAMES

Frame No.	Moisture
	%
1	17.9000
2	16.3222
3	15.7389
4	15.9667
5	16.3111
6	16.1667
7	17.0278
8	17.5056
9	19.4278
Necessary difference for significance ($P = .05$)	0.6112

GENERAL DISCUSSION

In previous work of the Bee Division (unpublished) it has been shown that when combs are considered as facing the central frame there is a high significant difference in the moisture of the honey from the two sides. However, when considering the combs as facing all in the same direction the results lack significance.

In some cases there seem to be decided differences in the moisture content of the honey from the different parts of the combs considered horizontally. Results presented indicate the highest moisture content occurring in the middle part. In the case of super No. 324 there was also significant difference between the moisture content of honey from End 1 (towards the front of the hive) and that from End 2 (towards the back of the hive).

In all cases the bottom part of the comb contained honey of significantly higher moisture content than either the central or the uppermost part. In all cases, too, the moisture content of the honey decreased towards the top of the comb and in No. 324 the difference was significant between the centre and top parts as well as very highly significant between the bottom and the other parts.

When considering the differences due to frames it is apparent that combs situated at, or near, the outside of the hive frequently contain the highest percentages of moisture. In the case of No. 202, honey from frame No. 1 is significantly higher in moisture content than all others, while frame No. 7 is significantly lower. The moisture content of frame No. 1 is so much greater than the rest that it would appear as if the honey had been put into the cells just recently. Since all cells were capped it certainly indicates that bees will cap honey before it is ripened and that ripening after capping is to be expected.

In the case of super No. 336, frames No. 8 and 1 are significantly higher than any others, while No. 9, the opposing outside frame to No. 1 is quite low in moisture content. Although only significantly lower than No. 1 and No. 4 this was also true of No. 9 super No. 202, so that it is not conclusively affirmed that combs situated at or near the outside of the hive necessarily contain the highest percentage of moisture, but since records regarding manipulation are lacking it may be that frame No. 9 in super 336 had previously been moved from nearer the centre and placed at the outside.

CONCLUSIONS

Studies conducted to determine the variation of the moisture content of honey in normally capped supers reveal differences of as high as 9.2% moisture in honey from a single comb and 10.7% within a super.

Statistical analyses of the data obtained show significant differences in the moisture content of honey: *(a)* from either side of a frame; *(b)* from one part of the comb to another considered horizontally; *(c)* from one part of the comb to another considered vertically; and *(d)* from frame to frame. Highest moisture content occurs in honey in cells situated as follows: *(a)* in the part designated middle (horizontally); *(b)* in the part designated bottom (vertically); *(c)* in frames nearest the outside of the super.

ACKNOWLEDGMENT

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APPENDIX

TABLE 1.—MOISTURE CONTENT OF CAPPED AND UNCAPPED HONEY FROM AN AVERAGE SUPER (SUPER NO. 202)

South Side

Frame No.	End 1			Middle			End 2		
	Top	Centre	Bottom	Top	Centre	Bottom	Top	Centre	Bottom
1	25.9	25.0	26.0	20.8	20.8	22.2	20.6	20.8	20.9
2	17.5	16.4	16.9	17.4	16.4	*17.9	18.0	16.5	18.0
3	17.8	16.2	17.3	16.4	18.4	18.7	16.2	16.5	16.4
4	16.3	16.4	17.1	16.6	16.8	†17.4	17.0	19.0	*20.0
5	17.2	*17.3	*17.6	17.2	*16.8	*17.2	18.4	*18.9	*19.2
6	16.4	17.3	16.9	16.5	*16.6	16.4	17.3	17.7	17.9
7	15.8	15.8	17.3	15.8	16.0	16.1	16.2	15.4	16.8
8	17.8	17.0	16.6	18.0	17.5	*16.6	17.7	17.0	16.3
9	16.7	16.2	17.0	16.8	*17.2	*17.2	17.3	17.1	*19.0

North Side

Frame No.	End 1			Middle			End 2		
	Top	Centre	Bottom	Top	Centre	Bottom	Top	Centre	Bottom
1	16.9	21.9	22.7	16.8	20.3	20.3	17.0	19.8	20.8
2	16.2	17.3	17.9	16.2	17.2	17.9	16.4	17.0	17.1
3	17.7	19.9	21.6	16.6	17.3	17.5	16.1	16.8	16.6
4	15.8	16.7	16.8	17.4	17.3	†18.0	18.1	21.1	20.9
5	16.1	16.6	16.3	16.8	17.2	16.2	17.2	18.7	18.0
6	19.0	16.4	16.8	18.9	16.8	16.6	19.4	16.6	17.8
7	16.6	15.5	15.8	17.5	16.7	16.6	17.4	15.7	17.2
8	17.6	16.1	16.8	16.6	17.7	16.6	17.2	15.3	16.5
9	17.0	15.8	16.6	16.9	17.8	17.4	17.1	16.2	16.6

† Filled missing reading by method of Allan and Wishart (1).
* Indicates readings on uncapped honey.

TABLE 2.—MOISTURE CONTENT OF CAPPED AND UNCAPPED HONEY FROM AN AVERAGE SUPER (SUPER NO. 336)

East Side

Frame No.	End 1			Middle			End 2		
	Top	Centre	Bottom	Top	Centre	Bottom	Top	Centre	Bottom
1	17.4	17.3	*17.1	17.7	17.2	21.6	17.7	*20.4	*20.6
2	15.5	15.8	16.3	15.8	16.2	16.4	16.4	16.1	16.8
3	15.8	15.9	15.6	16.1	16.6	14.9	16.8	16.2	15.6
4	15.6	15.6	16.2	15.9	*16.6	19.8	17.2	16.8	15.9
5	16.6	15.8	15.8	16.4	*19.0	*19.4	17.2	16.3	16.2
6	17.4	16.4	15.8	16.6	*19.0	*19.6	16.4	15.3	15.8
7	16.8	16.3	16.8	16.8	16.6	*19.6	17.1	16.4	16.2
8	17.4	*20.2	*19.8	17.5	*19.6	*19.6	17.4	*20.4	*20.0
9	16.2	16.0	16.5	16.4	16.1	17.0	16.8	16.9	16.6

TABLE 2.—MOISTURE CONTENT OF CAPPED AND UNCAPPED HONEY FROM AN AVERAGE SUPER —*Concluded*

West Side

Frame No.	End 1			Middle			End 2		
	Top	Centre	Bottom	Top	Centre	Bottom	Top	Centre	Bottom
1	17.3	16.6	18.9	18.0	17.2	17.8	18.6	17.0	18.2
2	15.8	16.0	16.1	16.5	16.0	15.8	16.4	15.7	15.7
3	16.9	15.4	16.7	16.8	16.2	*19.5	17.7	17.0	16.3
4	16.3	16.6	16.0	16.4	19.1	20.2	16.6	16.4	15.8
5	16.3	15.8	16.5	17.7	*19.6	*19.6	17.0	16.9	16.0
6	17.4	16.1	16.6	16.4	*19.1	*19.8	17.3	16.4	16.3
7	17.0	16.8	17.2	16.5	16.6	*19.0	17.4	16.1	16.4
8	18.8	17.0	18.6	17.4	16.6	16.8	17.8	17.7	17.4
9	16.3	16.2	16.6	15.9	16.2	16.4	16.4	16.1	16.3

* Indicates readings on uncapped honey.

TABLE 3.—MOISTURE CONTENT OF CAPPED AND UNCAPPED HONEY FROM AN AVERAGE SUPER (SUPER NO. 324)

East Side

Frame No.	End 1			Middle			End 2		
	Top	Centre	Bottom	Top	Centre	Bottom	Top	Centre	Bottom
1	17.3	17.8	*22.2	17.1	17.6	17.3	17.2	17.4	18.7
2	15.6	16.0	16.4	15.8	16.1	*20.6	15.6	16.0	16.4
3	15.2	15.4	16.2	14.8	15.8	*16.5	14.8	15.4	15.6
4	15.3	15.5	16.1	14.9	16.2	18.9	15.0	15.2	16.2
5	15.8	15.6	*19.2	16.2	15.6	*18.3	16.3	15.2	16.0
6	16.0	16.1	15.8	15.7	15.6	*20.2	15.6	15.8	16.4
7	15.9	16.3	*19.8	16.1	16.1	*19.3	16.0	15.7	16.5
8	16.6	16.8	*19.8	16.4	16.0	*18.8	15.6	15.8	16.6
9	16.9	17.9	*20.8	17.0	*20.4	*20.4	16.2	17.0	*20.6

West Side

Frame No.	End 1			Middle			End 2		
	Top	Centre	Bottom	Top	Centre	Bottom	Top	Centre	Bottom
1	16.6	17.2	18.2	17.4	16.8	*22.0	17.0	16.7	17.7
2	15.8	15.9	16.8	17.1	15.7	*16.2	15.8	15.8	16.2
3	15.2	15.2	15.8	15.9	15.8	*19.1	15.4	15.6	15.6
4	15.2	16.4	16.5	15.3	15.5	*18.8	15.4	15.2	15.8
5	15.9	16.1	16.3	15.2	16.2	*18.8	15.3	15.2	16.4
6	15.5	16.1	17.1	15.7	16.1	*16.5	15.1	15.7	16.0
7	16.0	16.8	*20.0	16.2	18.0	*19.5	15.9	16.0	16.4
8	16.2	17.6	*20.4	16.2	20.2	*19.3	15.8	16.4	*20.6
9	18.3	*21.2	*21.8	17.6	*21.4	*21.2	17.8	*21.4	*21.8

* Indicates readings on uncapped honey.

It may be noted that the data for No. 202 are listed under South Side and North Side. In this case the hive was facing West while Nos. 336 and 324 were facing South, and the data are listed under East Side and West Side.

SEASONAL CHANGES IN EASILY-SOLUBLE MANGANESE IN APPALACHIAN PODSOL SOIL[1]

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During the summer of 1938 the seasonal changes in easily-soluble manganese were followed in certain of the fertility plots established by the Macdonald College Soil Fertility Committee. Although the results of one season only are available, it is thought that the indications obtained are of sufficient interest to warrant bringing them to the attention of other soil workers. The plots in question are located on a soil of the Appalachian upland podsol type. Some of the distinguishing characteristics of this type of soil have recently been described (1). The plots sampled had received the following treatments:

Nil.
1.5 tons of limestone per acre.
3.0 tons of limestone per acre.
3.0 tons of limestone and 30 pounds of borax per acre.
3.0 tons of limestone plus 1.26 tons of magnesium carbonate per acre.

The limestone and magnesium carbonate treatments were applied to the fall-plowed sod in the autumn of 1937, the borax in the spring of 1938 just prior to seeding to hay with oats as the nurse crop. Sampling was done under this crop during the succeeding summer. The plots were 1/200 acre in area. They were duplicated on each of two farms. Six uniformly distributed borings were taken on each sampling date from each of the duplicated plots on each of the farms. The soil so obtained was mixed to give a composite sample per treatment per farm, from which the portion for analysis was drawn by quartering. On reaching the laboratory from 12 to 24 hours later all samples were air-dried and passed through a 2 mm. sieve before analysis.

The easily-soluble manganese was extracted by the dilute acetic acid method of McCool (2). Five grams of air-dry soil were placed in one litre of N/5 acetic acid solution in 2.5 litre bottles. The latter were shaken by hand for 1 minute each hour for 5 hours, the filtrate evaporated to small volume, and the manganese extracted determined by the periodate oxidation method of the A.O.A.C., the colour comparisons being made in a Campbell-Hurley colorimeter.

The results obtained are summarized in Table I. The values given in this table are the averages of those obtained from the two farms. There were 10 analytical samples for each date. The various treatments had very little effect on the amounts of soluble manganese found, as is indicated by the comparatively small average deviations from the mean values. No determinations of the effect of the applications of limestone on the pH of

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these plots were made in 1938. However, it is known from previous work on neighbouring farms (3) that the pH values on the limed plots must have been 1 to 1.5 pH units greater than on the unlimed plots. Comparison of the results from limed versus unlimed plots did not indicate at any time in the season a significant effect of liming on the amount of manganese extracted.

McCool (2) has reported data on water-soluble manganese in soils in the field in which an August maximum for this soil constituent is shown. Our results for N/5 acetic acid-soluble manganese differ from those of McCool in that maxima are found in May, late in June, and mid-July, with decided minima on June 14 and August 30. The extremes found in

TABLE I.

Date	P.p.m. soluble manganese in air-dry soil	Mean soil temps. (°F. at a depth of 4 inches) between sampling dates	Mean daily precipitation in inches between sampling dates	Remarks
10/5/38	35.8 ± 3.0	—	—	Before seeding.
27/5/38	36.4 ± 3.1	51.0	0.23	—
14/6/38	26.9 ± 2.2	61.0	0.06	Crop suffering from drought.
28/6/38	36.3 ± 2.7	67.0	0.20	—
19/7/38	35.6 ± 3.4	63.5	0.16	Oats heading.
30/8/38	21.8 ± 2.6	67.7	0.15	After harvest.
15/9/38	29.2 ± 1.4	56.5	0.17	—
30/9/38	31.2 ± 1.6	51.0	0.20	—

the present study are believed to indicate an important soluble manganese-soil moisture relationship. The correlation of soluble manganese with precipitation seems especially evident for the period May 27 to June 28. With regard to the July 19 to September 15 interval, it will be noted that the August 30 minimum occurs after a period of high temperature and of medium, but not low, precipitation. However, between July 19 and August 30 the crop transpiration rate must have been high for at least a part of the time, since on the former date the crop was just coming into head. Further, the mean temperature for this period would indicate a high rate of evaporation from the soil. Consequently it would appear that an influence of soil moisture upon the solubility of manganese may be assumed in this instance also.

McCool has reported (2) that holding soils at high moisture content in the laboratory increases the amount of water-soluble manganese. Our results indicate a similar relationship of moisture content to acetic acid-soluble manganese in the field. The fact that the soils were air-dried before analysis suggests that there is a decided time factor in the response of manganese solubility to soil moisture content. This has also been indicated for water-soluble manganese in the laboratory experiments of McCool.

The results shown in Table I suggest that damage from "grey speck" of oats in manganese-deficient soils may be expected to be more severe in

warm dry springs. This has, in fact, been the experience of those working with "grey speck" on the Macdonald College farm. No determinations of acetic-acid soluble manganese have as yet been made on this latter soil.

Finally it may be noted that the amounts of manganese soluble in N 5 acetic acid found in this study of an Appalachian upland podsol are, as compared with those found by McCool for a variety of soils, medium in quantity.

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OBSERVATIONS ON THE EASILY-SOLUBLE PHOSPHORUS IN A SOIL OF THE APPALACHIAN UPLAND PODSOLIZED TYPE[1]

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Recent studies in this laboratory (5, 12, 18, 19, 20) have indicated the presence of considerable amounts of organically-combined phosphorus in certain soils of Eastern Canada. In view of the proportions of this fraction which appear to be present in some instances, and in view of its solubility in strongly acid solutions, it was thought desirable to investigate the following possibilities:

(a) That the usual reagents employed for the estimation of easily-soluble ("available") phosphorus in soils might extract some phosphorus in organic combination;

(b) That there might be a conversion of easily-soluble organic phosphorus compounds to inorganic phosphate during the growing season.

In addition, some observations have been made on the accuracy of the method of determination employed, and also on the stability of the easily-soluble fraction of the organic phosphorus extracted.

Unless otherwise noted the soil samples used in these studies were obtained from the experimental plots of the Macdonald College Soil Fertility Committee located in the vicinity of Sawyerville, Quebec. Samples were taken during the summers of 1938 and 1939 from plots receiving the following treatments:

Nil.
1 5 tons of limestone per acre.
3 tons of limestone per acre.
3 tons of limestone and 30 pounds of borax per acre.
3 tons of limestone and 1.26 tons of magnesium carbonate per acre.

The limestone and the magnesium carbonate were applied to the fall-plowed sod in the autumn preceding the taking of samples. The borax was applied in the spring of the year of sampling in each instance. All plots were seeded to hay, with oats as the nurse crop unless otherwise specified. Sampling was done under this crop in both years. The plots, which were 1/200 acre in area, were duplicated on each of two farms in each year. Six uniformly distributed borings to plow depth were taken with a soil auger on each date from each of the duplicate plots on the two farms. The soil so obtained was mixed to give a composite sample per treatment per farm from which the portion for analysis was drawn by

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quartering. On reaching the laboratory from 12 to 24 hours after sampling the soil was air-dried and passed through a 2 mm. sieve before analysis.

In 1939, in addition to studying the plots seeded to oats, another adjacent area of 1/40 acre fall-plowed sod on the H farm was kept fallow throughout the season and sampled at the same intervals as the oat plots. This fallowed area had received a dressing of about 10 tons per acre of manure the preceding autumn after being plowed. Analyses of the samples from this plot were made on the moist soil which was placed in tightly closed quart sealers for transportation to the laboratory.

In 1938 the acid calcium sulphate extracting solution described by Wrenshall and McKibbin (17) was used in the determination of the easily-soluble phosphorus. The inorganic phosphorus content of the extracts was estimated by the method of Truog and Meyer (15). A Campbell-Hurley colorimeter was employed for all the colorimetric measurements reported in this paper. The total phosphorus in an aliquot of the extract was determined by the same procedure after oxidation with magnesium nitrate solution followed by hydrolysis with hydrochloric acid. The difference between the total and the inorganic phosphorus contents of the extracts thus determined was considered to have been due to phosphorus in organic combination, since the available evidence indicates that organically-combined phosphorus does not take part in the ceruleo-molybdate reaction. No difficulty was experienced in obtaining non-turbid extracts from these soils, hence it was assumed that the phosphorus of the clay fraction was not an interfering factor. All results are reported as parts per million of air-dry soil.

The amounts of easily-soluble phosphorus found during the season of 1938 were very small, and since it was known (17) that the quantities extracted from a soil of this type by the acid ammonium sulphate reagent of Truog (14) were somewhat greater than those removed by the acid calcium sulphate solution, and since these larger amounts could be measured with somewhat greater accuracy, it was decided to utilize the Truog extracting solution in 1939. Experiment showed that, when these two extracting solutions were used on the 1939 samples from the H farm, the amounts of phosphorus extracted by the acid calcium sulphate solution were similar to those found in the samples from the B and the McK farms in 1938, and that the quantities of phosphorus removed by the Truog reagent were 36 $\pm$ 5% greater. Fourteen comparative determinations were made.

In 1939 observations were also made on the accuracy of the determination of easily-soluble phosphorus under the analytical conditions adopted. In this study a single operator (P.L.A.) made all the colorimeter readings. The colorimeter was placed in front of a north window with the mirror focussed on the sky. The comparisons were made on 11 separate days over the period June 15 to Sept. 21. A wide range of light and sky conditions was encountered. Twenty-three different concentrations of standard unknowns ranging in phosphorus content from 0.02 to 0.15 p.p.m. were compared against a single known standard having a concentration of 0.1 p.p.m.. The latter standard was used in all the comparisons reported in this paper. The unknown solutions were prepared by a different worker (W. A. DeL.), who selected concentrations at random.

These concentrations were not revealed to the operator. Four determinations in all were made at each concentration of the unknown solutions, and in no instance were all these made on the same day. The operator developed the colours in all the solutions. This was done simultaneously for two unknowns and the standard. The pair of unknowns could be compared against the standard within 10 minutes from the time the colours were developed. Colour fading was negligible for this period. It was established that this operator's mean error of reading the instrument, as given by the mean value of the average deviations of the scale readings for the 23 sets of quadruplicate determinations, was 2.1 scale units. That is, the error of reading the instrument was about $\pm 4\%$ when 50 ml. aliquots of unknown and standard of approximately equal concentration were used. It is this error which is of particular importance in the present investigation, which is, for the most part, concerned with comparative measurements within a relatively narrow concentration range.

The theoretical colorimeter readings for the standard unknowns were calculated and compared with those actually obtained by the operator. Examination of the results showed that, when 50 ml. aliquots of unknown were compared against 50 ml. of standard solution containing 0.1 p.p.m. of phosphorus, the concentration of the former must lie within the range 0.07 to 0.15 p.p.m., otherwise the error of the determination would exceed $\pm 10\%$. In other words, if a 2-gram sample of soil was extracted with 400 ml. of Truog reagent, and 50 ml. of the extract was used for comparison against a standard containing 0.1 p.p.m. of phosphorus, the easily soluble phosphorus extracted from the soil might be estimated with an error of comparison not greater than $\pm 10\%$, provided that the soil contained not less than 14 nor more than 30 p.p.m. of this component. It was further found that, when the amounts of easily-soluble phosphorus were less than 24 p.p.m. of soil, the values obtained were consistently too high, and that the positive error of the comparison became progressively greater with increasing dilution.

When 25 ml. aliquots of the standard unknowns were compared against 50 ml. of the 0.1 p.p.m. standard—this was done for the higher concentrations of the unknowns—the $\pm 10\%$ limits were 0.09 to 0.15 p.p.m. These values correspond to 36 and 60 p.p.m. of easily-soluble phosphorus in the soil when extracted according to Truog's method. A considerable number of the determinations on the 1939 samples were made in this manner.

It will be noted that some of the values given in this paper fall outside the $\pm 10\%$ limits given above. The reason for this is that the study of the accuracy of colour comparisons was not completed until relatively late in the summer of 1939, and the magnitude of the error involved was not fully appreciated. The higher values falling outside this range are more nearly correct than the lower since in the determination of the former the soil extract was more highly diluted before colour development or smaller aliquots were taken after colour development for comparison with the standard. The effect of either of these procedures was to bring the concentrations of the solutions compared within the $\pm 10\%$ range. Further, as already pointed out, comparative results were sought rather than accurate determinations of the amounts of easily-soluble phosphorus present, and

it is believed that the accuracy attained is sufficient for the purposes of this investigation.

The results of these studies may conveniently be reported in two sections: Seasonal studies of easily-soluble phosphorus; and investigation of the effects of various conditions on the quantity of easily-soluble phosphorus extractable from the soil and on the stability of the organic phosphorus compounds in the extract. The latter will, for brevity, be styled, Investigation of Effects of Conditions.

RESULTS OF SEASONAL STUDIES

In 1938 the amounts of easily-soluble phosphorus found in the samples taken from the experimental plots on the two farms (B farm and McK. farm) were found to be closely similar. The differences for different treatments, and between the two farms, at any given sampling date were small and could not be regarded as significant. Consequently, only the mean values for the 10 samples analysed on each date, 5 from each farm, are reported. The values found are given in Table 1.

TABLE 1.—AVERAGE EASILY-SOLUBLE PHOSPHORUS CONTENT (QUEBEC REAGENT) DURING THE SEASON OF 1938

Sampling date	Easily-soluble phosphorus in parts per million of soil*		Remarks
	Inorganic	Organic	
May 10	5.5	5.1	Before seeding.
May 27	6.2	4.3	—
June 14	6.8	2.5	Crop suffering from drought.
June 28	3.3	4.2	—
July 19	3.6	3.9	Oats heading.
Aug. 30	5.8	7.0	After harvest.
Sept. 15	5.3	3.6	After harvest.
Sept. 30	4.6	3.8	After harvest.

* Extractions made with the acid calcium sulphate solution of Wrenshall and McKibbin (14).

TABLE 2.—EASILY-SOLUBLE PHOSPHORUS CONTENT (TRUOG REAGENT) DURING THE SEASON OF 1939

Sampling date	Easily-soluble phosphorus in parts per million of soil*						Remarks
	M farm		H farm		H farm fallow†		
	Inorg.	Org.	Inorg.	Org.	Inorg.	Org.	
May 18	18.9	8.4	8.0	8.9	10.4	13.6	Before seeding.
June 2	18.4	5.7	7.8	6.4	17.8	4.6	—
June 19	17.8	7.7	8.4	5.7	11.3	6.7	—
July 4	17.9	7.6	9.3	7.7	12.7	4.3	—
July 14	17.3	8.6	11.1	5.6	12.2	3.7	Oats heading.
July 28	—	—	—	—	14.0	3.3	—
Aug. 19	12.2	7.6	7.7	8.1	11.7	6.1	After harvest.
Sept. 5	—	—	—	—	9.8	7.0	After harvest.
Sept. 19	—	—	—	—	11.0	6.3	After harvest.

* Extractions made with the acid ammonium sulphate solution of Truog (14). The M farm and H farm samples were air-dried before extraction while the H farm fallow samples were extracted at approximately the moisture content obtaining in the field at the time of collection.

† These samples were not treated with chloroform.

In 1939, on the other hand, there was found to be a considerable difference in the easily-soluble phosphorus content of the samples from the two farms (H farm and M farm). The results for these two sites are therefore reported separately in Table 2. Since the results for the different treatments were similar to those of 1938, that is, no significant differences were found, only the mean values for all the treatments are recorded. Table 2 also includes the values found on analysis of the moist samples from the fallowed plot adjacent to the experimental area on the H farm.

Examination of the results reported in Tables 1 and 2 shows that an appreciable proportion of the total easily-soluble phosphorus in these soils may be considered to be in organic combination. In some instances this amounts to 50% or more of the total phosphorus extracted by the acidic reagents used. It may be noted at this point that other work in this laboratory has shown (3) that the podsolized soils of Nova Scotia also contain phosphorus in organic form extractable by the Truog reagent. In the Nova Scotian soils the easily-soluble organic phosphorus varied from 1 to 2% of the total in soils high in extractable phosphorus (200 p.p.m.) to 65% of the total in an uncultivated unfertilized soil under sod, and for the 9 soil types investigated (including one salt marsh and one dyked marsh, both of which contained easily-soluble organic phosphorus) averaged 25% of the total phosphorus extracted by the Truog reagent. The organic fraction of the easily soluble phosphorus extracted from the calcareous loam soil of the Macdonald College farm has been found, in the few determinations made, to be a small fraction of the total (200 p.p.m.), less than 10% of the latter.

From the data of Tables 1 and 2 it is also seen that the seasonal variation in the amount of easily-soluble phosphorus present in the soils of the experimental plots studied is relatively small. Further, there appears to be some evidence that conversion of easily-soluble organic compounds of phosphorus to inorganic compounds of similar solubility occurs. Thus, a comparison of the amounts of organic phosphorus in the samples obtained at the first sampling in each season with those found at the second sampling shows the values on the latter date to be lower in all instances. In addition, there is for the 1938 samples and also for the 1939 fallow plot samples, a concurrent rise in easily-soluble inorganic phosphorus. That such a conversion might result from the rising temperature and decreasing moisture content at this time of the year is indicated by the results reported in the next section of this report.

It must be emphasized at this point that only the easily-soluble organic phosphorus brought into solution by extraction with an acidic reagent has so far been investigated. There is also present in these soils organic phosphorus which may be extracted with dilute alkaline reagents (12). No attempt has as yet been made to study the seasonal behaviour of this fraction of the soil phosphorus, and increases in acid-extractable inorganic phosphorus coincident with decreases in acid-extractable organic phosphorus have been assumed to be the result of conversion of the latter to the former. Further, the possibility that disappearance of acid-soluble organic phosphorus may be the result of increased insolubility of this fraction has not been excluded. Crucial experimentation on this point is difficult since the organic phosphorus easily soluble in dilute acidic

solutions is a very small fraction of the total organic phosphorus present in these soils, and because of the fact that these soils possess a considerable fixative power for inorganic phosphorus, as a consequence of which the phosphate produced by decomposition of organic phosphorus compounds may rapidly be rendered insoluble. More conclusive evidence of the lability of the easily soluble organic phosphorus extractable by dilute acidic solutions is presented in the following section of this report.

The very considerably higher levels of extractable phosphorus found in the fallowed as compared with the adjacent cropped soil on the H farm is no doubt due, in part at least, to the fact that the former had received an application of manure the previous autumn.

It may be noted that the seasonal trend in content of total easily-soluble phosphorus for the soil of the fallowed plot followed somewhat the same general course as the biological activity in this soil, the latter being measured by carbon dioxide production in the laboratory. Both series of values showed a seasonal decline and their correspondence was most marked during the period from June 2 to July 14. The carbon dioxide determinations were made by the Bacteriology Department at Macdonald College on portions of the same samples used in the analyses for easily-soluble phosphorus (7).

INVESTIGATION OF EFFECTS OF CONDITIONS

Addition of Chloroform as a Preservative

During the season of 1938 it came to be suspected that air-drying of the samples before analysis was having an effect on the amount of easily-soluble phosphorus extracted. Accordingly, it was decided to study this possibility in 1939, using the samples from the fallowed plot as experimental material. In view of the likelihood that microbiological action during transit to the laboratory might have an appreciable influence on the easily-soluble phosphorus content, it was decided to take duplicate samples, one to be placed in a tightly closed quart sealer without treatment, while to the other sample in a similar container a porcelain crucible containing absorbent cotton saturated with chloroform was to be added. The first of these sealers was filled with soil, the second nearly filled, leaving just sufficient space at the top to contain the crucible. The containers were placed in an upright position during transit so that the heavy chloroform vapour would penetrate through the whole of the treated sample. As soon as possible after arrival at the laboratory the moist samples were sieved through a 2 mm. sieve and the moisture content determined by toluene distillation. When the percentage of moisture had been ascertained sub-samples of sufficient weight to contain 2 grams of air-dry soil were taken for analysis. The analytical results obtained on a series of such duplicate samples taken throughout the season are given in Table 3.

It is evident from Table 3 that the chloroform treatment has resulted in a consistently higher content of extractable inorganic phosphorus. This difference may be explained either as the result of microbiological absorption of easily-soluble inorganic phosphate from the untreated soil during transit, or, as the result of the death of the micro-organisms in the treated soil. Possibly both processes are operative. However, in view

of the fact that it has been shown (13) that on addition of a lethal concentration of chloroform to aqueous suspensions of plankton inorganic phosphorus is liberated by post-mortem enzymatic action, the writers are inclined to the belief that similar post-mortem changes may be mainly responsible for the observed differences in extractable inorganic phosphorus

TABLE 3.—EFFECT ON THE EASILY-SOLUBLE PHOSPHORUS CONTENT (TRUOG REAGENT) OF ADDING CHLOROFORM TO MOIST SOIL

Sampling date	Easily-soluble phosphorus in parts per million of soil					
	Chloroformed sample		Untreated sample		Difference	
	Inorg.	Org.	Inorg.	Org.	Inorg.	Org.
May 18	14.4	12.8	10.4	13.6	+4.4	−0.8
June 2	20.8	6.4	17.8	4.6	+3.0	+1.8
June 19	16.8	7.8	11.3	6.7	+5.5	+1.1
July 4	19.3	6.3	12.7	4.3	+6.6	+2.0
July 14	18.7	Lost	12.2	3.7	+6.5	?
July 28	20.4	3.6	14.0	3.3	+6.4	+0.3
Aug. 19	16.4	10.0	11.7	6.1	+4.7	+3.9
Sept. 5	14.0	7.6	9.8	7.0	+4.2	+0.6
Sept. 19	16.4	3.3	11.0	6.3	+5.4	−3.0

between the individual pairs of differently treated soil samples. They further suggest that enzymes liberated by the death of the soil microorganisms might also hydrolyse a part of the organic phosphorus of the soil particles with which these organisms were associated.

Air-drying

An estimate of the effect of air-drying on the easily-soluble phosphorus content of these samples may be obtained by comparison of the values obtained after air-drying with those obtained for the moist samples which were not treated with chloroform. Such a comparison was found to indicate that drying increased the content of extractable inorganic phosphorus. The effect upon the easily-soluble organic phosphorus was much less consistent. In this connection it may be noted that, since the organic fractions are determined by difference, the combined errors of the determinations of inorganic and total phosphorus extracted render the values obtained for this fraction less reliable than those found for inorganic phosphorus. Some of the results obtained in this comparison are given in Table 3A.

TABLE 3A.—EFFECT OF AIR-DRYING ON EASILY-SOLUBLE PHOSPHORUS CONTENT (TRUOG REAGENT)

Sampling date	Easily-soluble phosphorus in parts per million of soil			
	Moist untreated sample		Air-dried untreated sample	
	Inorganic	Organic	Inorganic	Organic
May 18	10.4	13.6	15.8	7.0
June 2	17.8	4.6	12.0	4.6
June 19	11.3	6.7	13.4	7.0
July 4	12.7	4.3	14.0	2.8
July 14	12.2	3.7	19.0	6.6

A more extensive experiment on the effect of drying with the application of heat is reported below.

Desiccation

Extensive investigations on the effect of drying soils upon their content of easily-soluble components, including inorganic phosphorus compounds, have been carried out (1, 4, 8, 9, 10, 11, 16). In general, such studies indicate that on drying, either at ordinary or at elevated temperatures, the solubility of the soil phosphorus in water or in dilute acid solutions is increased. They also indicate that the increase in solubility is greater the higher the temperature of desiccation. However, it does not appear that any investigation of the effect of drying on the easily-soluble organic phosphorus of soils has previously been made.

The untreated (with chloroform) samples taken from the fallowed plot on July 28, and August 19, 1939, respectively, were sieved through a 2 mm. sieve, and placed in an electric oven at a temperature of 105° C. as soon after arrival at the laboratory as possible. These samples remained continuously in the oven at this temperature for the periods stated in Table 4, in which the effect of this treatment on the easily soluble phosphorus content is also shown. (It may be noted that the chloroform-treated samples behaved similarly under the same heat treatment.) On September 10, the automatic temperature control on the oven containing these samples accidentally went out of adjustment and the temperature rose to 140° C. The period between September 10 and 17 was one of fluctuating temperature (90° to 140°) while repairs were being made; on the latter date stabilization at 105° was again attained.

TABLE 4.—EFFECT OF DRYING AT ELEVATED TEMPERATURES ON THE EASILY-SOLUBLE PHOSPHORUS CONTENT (TRUOG REAGENT) OF THE FALLOWED SOIL

Time in oven	Easily-sol. P in p.p.m. of soil July 28 sample		Time in oven	Easily-sol. P in p.p.m. of soil August 19 sample	
	Inorganic	Organic		Inorganic	Organic
Zero *	20.4	3.6	Zero*	11.7	6.1
2 days	17.6	17.2	1 day	17.6	9.4
5 days	23.1	27.1	4 days	16.4	16.7
8 days	26.4	31.8	7 days	16.8	14.4
11 days	36.2	59.8	10 days	17.2	18.8
19 days	60.6	53.4	15 days	20.5	17.1
21 days	58.0	42.8			
24 days	67.2	43.2			
27 days	66.0	34.4			†
45 days	107.0	33.8	18 days	18.2	15.4
			21 days	41.6	35.2
			24 days	46.4	49.6 ‡
			28 days	52.8	46.8
			31 days	53.2	28.4

*Analyses of moist samples on arrival at the laboratory.

†The oven temperature rose to 140° C. on the 42nd and the 17th days of heating the July 28 and August 19 samples respectively.

‡Oven temperature again stabilized at 105°.

The analytical results for both these samples show striking increases in the amount of easily-soluble organic phosphorus as a result of heat treatment. For the sample of July 28 this increase amounts in 11 days at 105° C. to more than 16 times the quantity of extractable organic phosphorus originally present. The increase shown in the sample taken on August 19 is considerably less marked. No adequate explanation can be offered for this difference. Further, in both samples the extractable organic phosphorus at first increases at a more rapid rate than the corresponding inorganic fraction. A rise in temperature to 140° produces a further large increase in easily-soluble phosphorus in both instances also. In addition, it is to be noted that after the eleventh day in the oven the easily-soluble organic phosphorus content of the July 28 sample decreases in amount while the extractable inorganic phosphate continues to increase. This behaviour strongly suggests that conversion of organic to inorganic phosphorus is taking place. However, no clear evidence of a similar transformation in the August 19 sample was obtained.

In connection with the suggested thermal decomposition of the easily-soluble organic phosphorus it may be noted that the isolation of phytic acid from soils of this type has recently been reported from this laboratory (5). Further, it has been shown (2) that phytic acid and its salts are unstable to heat, the former being more labile than the latter and liberating 75% of its phosphorus as inorganic phosphate on drying 48 hours under reduced pressure. However, the ferric salt, which is in the form in which phytic acid has been assumed to be present in the soil (5), is apparently quite stable to heat treatment (6).

Alternate Wetting and Drying

Simply re-moistening the air-dry chloroform-treated samples from the fallowed plot to their original moisture content and holding them in this condition for 24 hours was found to have no significant effect on either the extractable inorganic or organic phosphorus. However, repeated moistening and drying of these samples was found to have an interesting result, especially on the easily-soluble organic phosphorus content. The procedure followed was to re-moisten to the original moisture content, leave in this condition in stoppered flasks for 24 hours, and then to dry at 105° C. for a further 24 hours. This process was repeated five times. After the fifth drying the samples were removed from the oven, allowed to come to equilibrium with the moisture in the laboratory air, and analysed. The results obtained are shown in Table 5.

TABLE 5.—EFFECT OF ALTERNATE WETTING AND DRYING (AT AN ELEVATED TEMPERATURE) ON THE EASILY-SOLUBLE PHOSPHORUS (TRUOG REAGENT) OF THE FALLOWED SOIL

Sampling date	Easily-soluble phosphorus in parts per million of soil			
	Fresh soil		Wetted and dried soil	
	Inorganic	Organic	Inorganic	Organic
May 18	14.4	12.8	16.8	20.0
June 2	20.8	6.4	24.1	30.5
June 19	16.8	7.8	19.8	27.0
July 4	19.3	6.3	24.2	34.6
July 14	18.7	Lost	22.7	30.1

Examination of the data of Table 5 shows that the wetting and drying treatment has resulted in increases in both inorganic and organic phosphorus extractable by the Truog reagent. The proportionate increase in the latter is, however, much the greater and amounts on the average to 380% of the original amount of this component extracted. The maximum increase is 550%.

SUMMARY

1. The amount and nature of the phosphorus extracted from a soil of the Appalachian upland podsolized type by means of acid calcium sulphate and acid ammonium sulphate solutions have been investigated.

2. Observations have been made on the relative amounts of phosphorus extracted from this soil by acid calcium sulphate and acid ammonium sulphate solutions, and also on the accuracy, over a certain concentration range, of the visual determination of the amounts of phosphorus in the extracts using a Campbell-Hurley colorimeter.

3. It has been shown that treatment of moist samples of this soil with chloroform vapour over periods of 12 to 24 hours, usually the latter, results in appreciable changes in the amount of inorganic phosphorus extractable by the acid ammonium sulphate reagent. It is suggested that this increase is due to the activity of enzymes liberated on death of the soil micro-organisms.

4. It is shown that organic as well as inorganic phosphorus compounds are extractable from this soil by these reagents, and that the organically-combined phosphorus may constitute an important fraction of the total amount of phosphorus removed.

5. It is also shown that the seasonal changes in the phosphorus extractable by these reagents from either cropped or fallowed soil are small.

6. Indications have been obtained that there may be a conversion during the growing season of easily-soluble organic phosphorus compounds to inorganic compounds of a similar solubility. Further and stronger evidence of the lability of the extractable organic phosphorus fraction has been obtained from experiments on the effect of heating and the effect of alternate moistening and heating on samples of this soil.

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BOOK REVIEW

SNYDER, L. H.—1940. The Principles of Heredity. D. C. Heath Co. $3.50.

Laurence H. Snyder of Ohio State University produced the first edition of "The Principles of Heredity" in 1935 and now in 1940 a second volume has appeared involving changes and additions to bring the subject matter of this rapidly evolving science up to date.

The one most striking change in this new edition is the development of a new chapter dealing with "Giant Chromosomes". This is a most important phase which was just beginning to be unravelled at the time of the previous publication.

Many minor differences are found in the new edition, all of which are distinct improvements. The main ones are as follows:

1. Additional illustrations have been added to what was already a well-illustrated volume. One of these is a chart for testing colour-blindness.
2. The number of problems found after each chapter have been greatly increased and they have been numbered consecutively throughout the book, thus making reference much easier.
3. The chapter on "Probability" has had a section added dealing with the "Chi-Square Test of Mendelian Progenies"—three tables are included.
4. Considerable rearrangement and some addition has been made to the chapter on "Chromosome Aberrations".
5. The nomenclature has been brought up to date as far as possible and the excellent practice continued of using heavy type to emphasize a new term when first introduced in the text.

This volume, like its forerunner, provides an excellent test for the beginner in genetics. Unlike so many genetic texts so labelled, it is really an introduction to the subject. The author's style is simple, yet lucid and most readable. He has not allowed his subject matter to become immeshed in too much detail. Many students turned to Snyder's earlier edition to get a clear-cut statement of some basic idea. This revised volume will serve a like purpose.

L. C. RAYMOND.